3D NUMERICAL MODELLING AND MANIPULATION OF A SHOE LAST

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A thesis submitted in partial fulfilment of
the requirements of De Montfort
University for the degree
of Doctor of Philosophy

October 1998

De Montfort University in collaboration with
Saint-Petersburg State University of Technology and Design

Abstract

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1998

As global competition continues to increase causing market windows to shrink and product life cycles shorten, manufacturers today can no longer function without advanced design tools. These market pressures dictate that designers must embrace new, faster and better design technologies than ever before if they are to remain competitive. This is especially true in the shoe industry with the employment of up-to-date methods of design and manufacture. The development of modern CAD/CAM systems, the availability of powerful hardware at reasonable cost and vast improvements in colour graphics capabilities have made the automation of the footwear design process feasible at low cost. All of this economically justifies the creation of a system for direct shoe last design without a prototype model last.

A specific onscreen methodology of a shoe last design directly from individual anthropometric data has been proposed and evaluated. A numerical methodology for onscreen visualisation with application of a new scheme of segmentation of the last surface and further manipulation of the last elements in order to create new last styles have been developed. In order to achieve this, the principles of shaping the last, the laws governing its deformation when changing the heel height and the list of possible modifications to its shape have been defined. Five global manipulation procedures have been implemented, in particular those that relate to changing the heel height. Special software has been written to visualise the results.

Experimentation has proved the validity of the approach. Lasts of similar style but with different heel heights were measured and numerically modelled to compare with computer generated and modified last models. The accuracy proved to be within the limits of practical and traditional constraints.

Author Declarations

1. During the period of registered study in which this thesis was prepared, the author has not been registered for any other academic award or qualification.

2. The material included in this dissertation has not been submitted wholly or in part for any academic award or qualification other than that for which it is now submitted.

3. The research programme of which this dissertation is part has consisted of:

   3.1 The English Language course – Foreign Languages Department, St.-Petersburg State University of Technology and Design.
   3.2 "C" Programming course – Department of Applied Mathematics, St.-Petersburg State University of Technology and Design.
   3.3 Computer Design course – Department of Applied Mathematics, St.-Petersburg State University of Technology and Design.
   3.4 Psychology course - Department of Psychology, St.-Petersburg State University of Technology and Design.
   3.5 Participation in Research Colloquia. 20 papers published, 5 presentations made.
   3.6 Attendance at relevant research conferences.

4. The following methods and procedures have been proposed exclusively by the author:

   4.1 Shoe last design method from foot data.
   4.2 New segmentation circuit for lasts with horizontal cone top plane.
   4.3 The list of possible last surface manipulations.
   4.4 Procedure for changing the last heel height.
   4.5 Procedure for narrowing the seat section when increasing the heel height.
   4.6 Procedure for generating the front cone profile of the last.
   4.7 Procedures for shaping the last profile shank curve.
   4.8 Shoe last design method from foot data with further modifying of its initial form.

Acknowledgements

First of all, I would like to honour and thank Professor Alexander Komissarov who is not with us any more but who always sustained me with his encouragement and support and who was the ancestor of scientific approaches developed in this work.

I would like to express my profound gratitude to Dr. Ray Harwood, my Second Supervisor, for his support, help and advice throughout the duration of this project but also for his constructive criticisms without excessively intervening.

Also I would like to thank Dr. Mark Bradshaw. He has always provided substantial assistance and counsel from the inception of this project to its conclusion.

Many thanks also to Steve Weston, former Senior Lecturer at Footwear Design, who always had time to help with his valuable hints related to footwear design and manufacture.

My deepest gratitude and heartfelt thanks go to my parents. Without their support and belief in my abilities, this thesis may never have seen the light of day.

List Of Contents

List Of Figures

List Of Tables

List Of Appendices

Chapter 1. Introduction

As global competition continues to increase causing market windows to shrink and product life cycles shorten, manufacturers today can no longer function without advanced design tools. These market pressures dictate that designers must embrace new, faster and better design technologies than ever before if they are to remain competitive.

This is especially true in the shoe industry with the employment of up-to-date methods of design and manufacture.

Conventionally, shoe manufacturing begins with the design and manufacture of the shoe last that is a wooden or plastic foot-shaped form around which footwear is made. Thus, lasts are fundamental to shoe manufacture since they dictate the exact shape, size and fit of the shoes made on them. As a result, the last defines the comfort that is the major parameter of quality of footwear, provided if conforms to the geometrical parameters of the foot and the shoe last.

The 3D form of a model last serves as the main information base for designing tooling-up and working parts of shoe machines. In its turn, the last design depends on the anatomy of the foot as well as on fashion trends.

As a result, the design of footwear should include not only drawing out line contours of model on the last surface, but also the freeform definition of the design, i.e. the last. This is the practice of leading stylists in Italy.

Unfortunately, in practice it does not work because traditionally a last is designed and produced by one person, and mass produced by another. As a result there is a break in the design process, and hence design and manufacture of the last is a handicraft skill, individual for each enterprise.

In spite of the fact that the shoe last was invented several centuries ago, the process of its designing is so far based on personal intuitive experience of a last-maker, who produces a sample manually. Usually beginning with a model last, the technician will use filler to build up and a file to remove material until the required shape is arrived at. This process is highly iterative between designer and technician. Later copy engineering emerged, but this also required the application of the manually made last,. Thus, although shoes may be designed using CAD systems, the design and production of the last is still a totally manual operation, relying heavily on the skill of the last technician.

There is another problem: the fact that the relationship between foot shape and last shape is highly complex and largely unknown. There are no precisely developed and formulated rules, formulas or coefficients that allow foot measurement data to form a high-grade last shape. Moreover, the various last datum relationships are also unknown making it impossible to manipulate a CAD model accurately. There are no quantitative methods, expressed algorithmically in formulas, enabling the replacement of this process by computers.

In general, there is also an absence of uniform approach to the last modelling. However, it is safe to say that traditional techniques of manufacturing the model shoe last assume the development of a set of flat patterns (a bottom pattern of the last, longitudinal-vertical section, about nine transverse-vertical cross-sections of the main anatomical points of the foot) for control of the last manufacturing process. The character of a surface between shaping contours is very arbitrary, therefore the complex surface of the last can not be unequivocally designed.

Consequently the received form does not always correspond to the patterns, that has subsequently an effect for tooling-up designing and accuracy of surfaces adjustment. Ultimately, the designer is influenced by a last stock offered by the last manufacturers.

Thus, the characteristic of the shoe manufacture in the domination of empirical and copy methods of footwear and tooling-up design; the low accuracy and subjective factor of hand-operated modelling results in large costs of manufacture and constrains usage of CAD/CAM systems. This could be explained by that, until recently, there were no means for quantitative definition of the last surface and its unequivocal reproduction in a kind of a physical sample. Hence all available developments in this area could not be checked by practice.

But now the situation has changed: powerful hardware is available at reasonable cost, color graphics capabilities have vastly improved, machine tools with numerical control and some special developments in this area, in particular, by "Clarks" (DEVELOPMENTS IN COMPUTER-AIDED DESIGN FOR FOOTWEAR, 1996), have appeared which give an opportunity for such experimentation.

All of this economically justifies the creation of a system for direct last design without a prototype model last. Therefore the interactive design of the last on screen is of vital concern for the industry and would eliminate many problems, saving time and money. Thus a new problem now appears: to create the methodology of the last designing based on foot data and aesthetic design, which would be suitable for in CAD/CAM systems.

For this purpose it is necessary to analyze existing experience, to reveal the availability of rational elements, to take into account the requirements of standardization and «know-how» of footwear, to use biomechanical and anthropometric aspects for this problem and to develop mathematical methods of last designing from foot on the computer.

1.1 Background to the research

The objective of the work described in this thesis is the elaboration, development and validation of a methodology of shoe last design directly from foot data and manipulation of the last elements in order to create new styles, taking into account the investigations of determining concepts of the relationship between the foot and the last data.

This work was carried out as a part of the larger project which includes elaborations that have been undertaken at Leather and Shoe Department (St.-Petersburg State University of Technology and Design) since 1989 under the leadership of Professor Komissarov. The project concerns questions of the automation of shoe design (KOMISSAROV, 1992; KOMISSAROV and GORDEYEVA, 1996; GORDEYEVA, GOROCH and KOMISSAROV, 1996; GORDEYEVA, KOMISSAROV and GOROCH, 1996; GOROCH, 1996; GOROCH, GORDEYEVA and KOMISSAROV, 1996), creating non-contact foot-sizing device (KARAGEZYAN, KOMISSAROV, GOZMAN and

ORSHANSKIY, 1990; KOMISSAROV and others, 1991), system of direct computer shoe last design and manipulation process (KOMISSAROV, GORDEYEVA and GOROCH, 1996) and other aspects (KARAGEZYAN, KOMISSAROV, BISTROVA, NAZAROV and TARVERDYAN, 1989; KARAGEZYAN, KOMISSAROV, ALECKSEYEV and GOZMAN, 1992; KARAGEZYAN, KOMISSAROV and ARISLANOVA, 1991).

The analysis of current situation in the field of automation of footwear designing and manufacturing processes shows that the main tendency in the development of footwear CAD systems is creating a uniform system of computer footwear and tooling-up designing based on individual anthropometric data. Thus, the main problem is the absence of a uniform approach to designing the shoe last in a computer environment on the basis of an individual foot.

Despite the suitability of different methods of last design, all of them use average foot data. When designing individual footwear, the parameters of particular feet are simply taken into account by fitting the most suitable ready made last to the foot.

In the case of application of CAD technology, the main principles of individual footwear 3D designing are based on selecting the most appropriate last from the library of mathematical models of lasts made and measured earlier; the combination of mathematical models of two lasts with the purpose of creating a third one or local modifications of one mathematical model.

Therefore it is possible to conclude, that none of the existing CAD systems for footwear offers, so far, a technique of direct computer last designing from foot data. This constrains development of modern methods of automated footwear and tooling-up designing.

Furthermore, all available mathematical methods used in these systems are poorly suitable for the task of the last surface generating. The use of B-cubic splining curves through known surface points is the usual method for commercial CAD systems. But the use of spline-interpolation while describing a surface requires 10^3 - 10^4 3D readouts, so the modification of spline-surface with predictable results is hindered because of the large number of knot points. Also it is inconvenient and difficult to set individual points to provide complete smoothness of the surface.

In 1992, when considering the problem of the last design without the physical prototype Komissarov (KOMISSAROV, 1992 –1; KOMISSAROV, 1992 -2) developed a new method of last description by minimum number of Bezier patches. The last surface is set by use of predetermined contours of bottom pattern, profile and four-five cross-sections (these contours served as the boundaries for the patches of bicubic Bezier surface).

This method was comprehensively investigated by Goroch (GOROCH, 1996) and was tested by describing a great deal of real lasts for different purposes.

Goroch (GOROCH, 1996) proved that to set contours of the basic last patterns (bottom, profile, 4-5 cross-sections), the whole surface (between the contours) would correspond to the real last shape. So the method was suitable for defining the surface of the real last from flat samples.

However, the method had the following disadvantages:

- absence of transferring rules from the foot shape to the basic last contours;
- absence of rules for footwear designer methods for manipulating last contours whilst designing;
- manipulation of separate points was very labor-intensive and an unintuitive design technique.

Moreover, the researches of Goroch were connected to adjustment of the surface to already made lasts and did not give recommendations on how to define the surface when there was no prototype.

With the purpose to use this new method effectively for last design without a sample, it is proposed to overcome the following problems in the present thesis:

- when setting a framework of the surface (Fig. 1.1) an operator is to manipulate 3D data of each vector by appropriate projections; it is very difficult and requires special training for the operator;
- aspects of manipulating the surface, primarily, connected with changing the heel height, are not considered;
- flat contour of the last front cone profile is used which does not correspond to reality and results in additional effort to prepare data;
- this scheme of last contours (Fig. 1.1), although adequate, does not correspond to the location of control points on traditional lasts; and this complicates maintenance of last conformity with a particular foot.

1.2 Aims and objectives of the research

Research Aims

1. To critically evaluate existing systems and methodology of CAD/CAM shoe design.
2. To devise methodology for numerical characterization and manipulation of last design elements for use in 3D shoe CAD systems.

The research work includes the following:

- Critical evaluation of existing 3D modelling applications.
- Study of the existing work relating to 3D surface manipulation, particularly that relating to shoes and lasts.

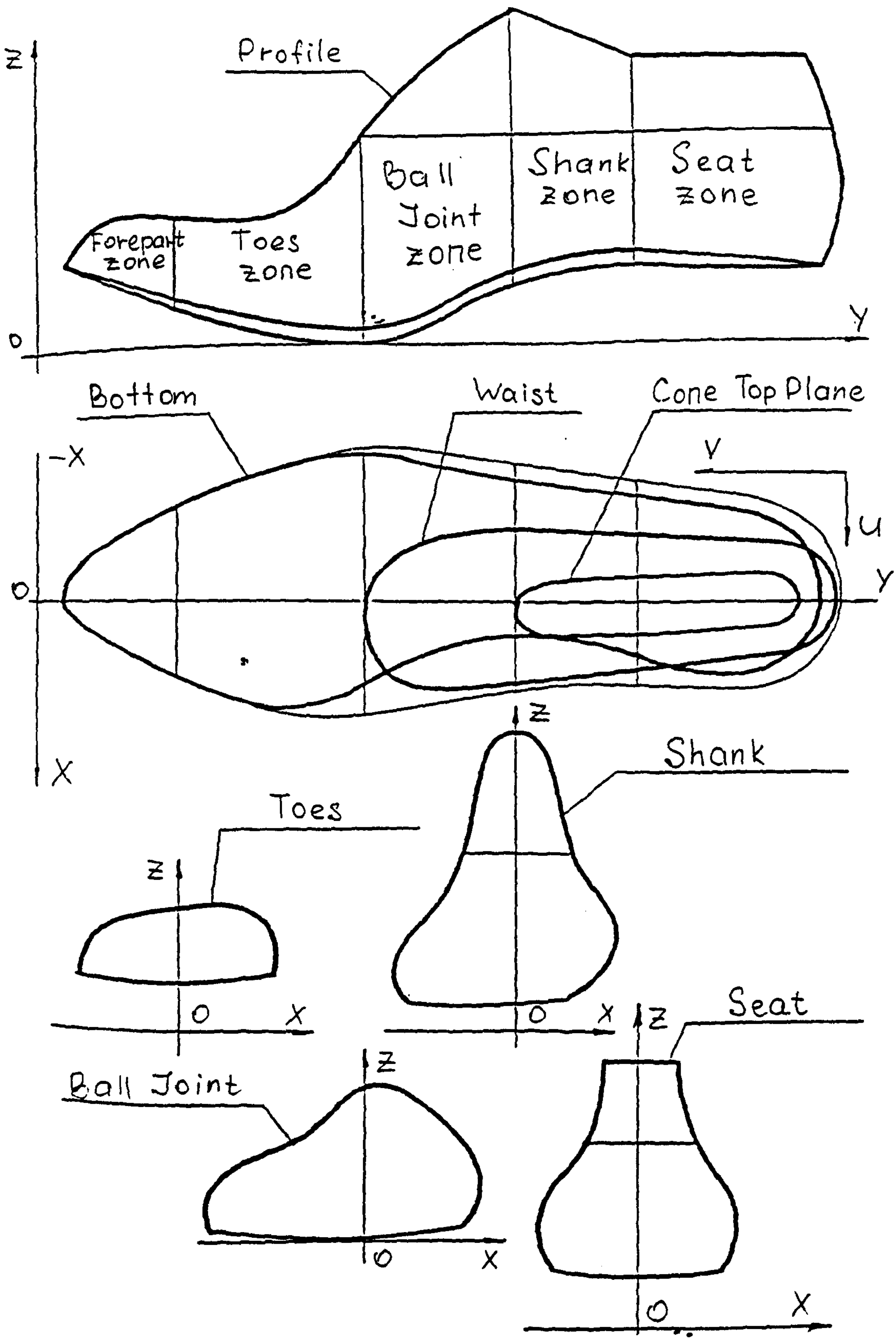


Fig. 1.1 The scheme of last surface segmentation

Study methodology potentially applicable to the representation and manipulation of 3D surfaces.

- Produce a critical survey of findings.
- Establish last datum relationships.
- Implement and evaluate a specific onscreen last manipulation methodology.
- Develop and evaluate a numerical methodology for onscreen visualization.

The objective of the present thesis is the development and evaluation of a technique of last design directly from foot data in mathematical-quantitative form, suitable for application of computer engineering, beginning from the foot/last relationship.

Hence to resolve these problems it is necessary:

1. To work out a technique of computer last design on the basis of method of a shoe last design without a physical prototype, earlier proposed by Komissarov (KOMISSAROV, 1992), that could facilitate:
- comfort design in interactive mode;
- transfer of foot sized data to a last shape;
- complete description of the last surface with an opportunity for manufacturing it by NC-means;
2. To analyze last shaping and reveal the areas concerned with anatomical, technological and aesthetic parameters;
3. To establish last datum relationships for those areas of the last which effect footwear comfort; to determine the primary parameters of the foot based on which last design would be undertaken;
4. To devise an arrangement of main contours of the last surface skeleton;
5. To develop algorithms and procedures for last surface manipulation in order to create a new style;
6. To design individual lasts by the invented technique.

1.3 Outline of thesis

The thesis is split into three sections. The first provides a detailed description of the problem and highlights the urgent need for this research (chapters 2, 3 & 4). The second describes the work undertaken and documents the results obtained (chapters 5, 6 & 7). The third draws conclusions and makes suggestions for further work (chapter 8).

Chapter 2 gives an introduction to anatomy and health of feet (2.1, 2.2) and shoe lasts history (2.3), details their types, definitions, specification and production techniques (2.4), gives the overview of footwear manufacture (2.5), paying particular attention to the types of shoe construction. Chapter 3 surveys foot (3.2) and last (3.3) measurement systems, evaluates foot and last measuring devices in order to choose optimal foot-sizing device for further research (3.2.1), describes sizing systems and classifies last sizing and fitting (3.4), compares Russian and the UK methods of last and upper patterns grading (3.4.2) and establishes the relationships between the foot and the last shape (3.5).

The feasibility of the task is supported by a survey into available shoe CAD/CAM systems (chapter 4), beginning from CAD technology history (4.2.1) and necessity (4.2.2), lists their common features (4.2.3) with emphasis on that work directly related to the last modelling (4.2.4). A survey of typical CAD/CAM systems is presented (4.2.5), followed by the conclusions (4.3).

Section two. Chapter 5 states the typical performance of current last design methods (5.1.1), describes the advantages of using unified last surface units for mass production (5.1.2), presents a new approach to the last design directly from individual foot data (5.2): describes the foot measuring experiment (5.2.1) and the methods devised for transferring obtained data to the last bottom pattern (5.2.3), profile design (5.2.4), cone top plane (5.2.5) and girths (5.2.6).

Chapter 6 deals with the methodology of numerical characterization of last surface and begins by a survey of common mathematical apparatuses applied in modern CAD/CAM systems for footwear (6.1), compares the Bezier curves with the B-splines (6.2), chooses the optimal mathematical algorithm for last surface description and proposes the new computerized methodology of applying the method of mathematical modelling the last surface from foot data.

Chapter 7 describes a methodology for last surface manipulation and documents the results obtained. In the beginning the last measuring by an automatic device is presented (7.1), then the chapter details various possible modifications of the last surface in order to create a new last shape (7.2) and the preliminary experiment for applying the modifications to the surface using MicroStation software (7.3). The results are presented and evaluated and the software disadvantages are discussed and analyzed, that proves the necessity of creating specific software for experimental research described in (7.4). The section culminates in the development of a methodology for manipulating the last surface global parts (7.5) including modifications, described in (7.2). The algorithms for manipulating heel height (7.5.2), toe spring (7.5.3), exact position of front cone profile (7.5.4) and shaping a profile shank (7.5.5) are devised and evaluated, and the new method for designing the last directly from the foot onscreen is fully evaluated.

Finally, conclusions are drawn and recommendations for further work are made.

Chapter 2. Footwear and Feet

It is a matter of fact that the last is designed from the foot form. Therefore, in order to design the last accurately it is essential to first study the foot structure as well as the biomechanics of the foot.

Much work has been carried out to study literature and examine shoe stylists, last-makers, physicians, orthopaedists in order to reveal anthropometric and biomechanic principles of the last design and parameters affecting footwear comfort. In the result foot disorders affected by ill-fitting footwear and graphical principles of the last design, were exposed.

2.1 Foot Structure

The human foot is a very complex organ. External foot shape is determined by the mutual arrangement of bones, ligaments and muscles. The bottom basic surface of the foot is referred to as the sole, and the upper as the top surface. The side surfaces are subdivided into outside (lateral) and internal (medial). On appearance it is possible to allocate two departments of the foot - forepart and back part.The forward part of the foot, especially in the toe area, is more movable and compressable than the back part.

BONES OF THE FOOT

Each foot consists of 26 bones. They are irregular in shape and in size. These bones provide 137 joints or articulations which permit movement of the foot, supply flexibility, and function as shock-absorbers when one is standing, walking, running or dancing. The bony architecture of the human foot is arranged in three main regions: the forefoot (phalanxes), midfoot (metatarsus) and rearfoot (tarsus) as shown in Figure 2.1.

- ***The Midfoot***

The five metatarsals that make the metatarsus are long shaft-like bones and function as levers or propellers in pushing the body weight forward as the foot rolls on the ball.

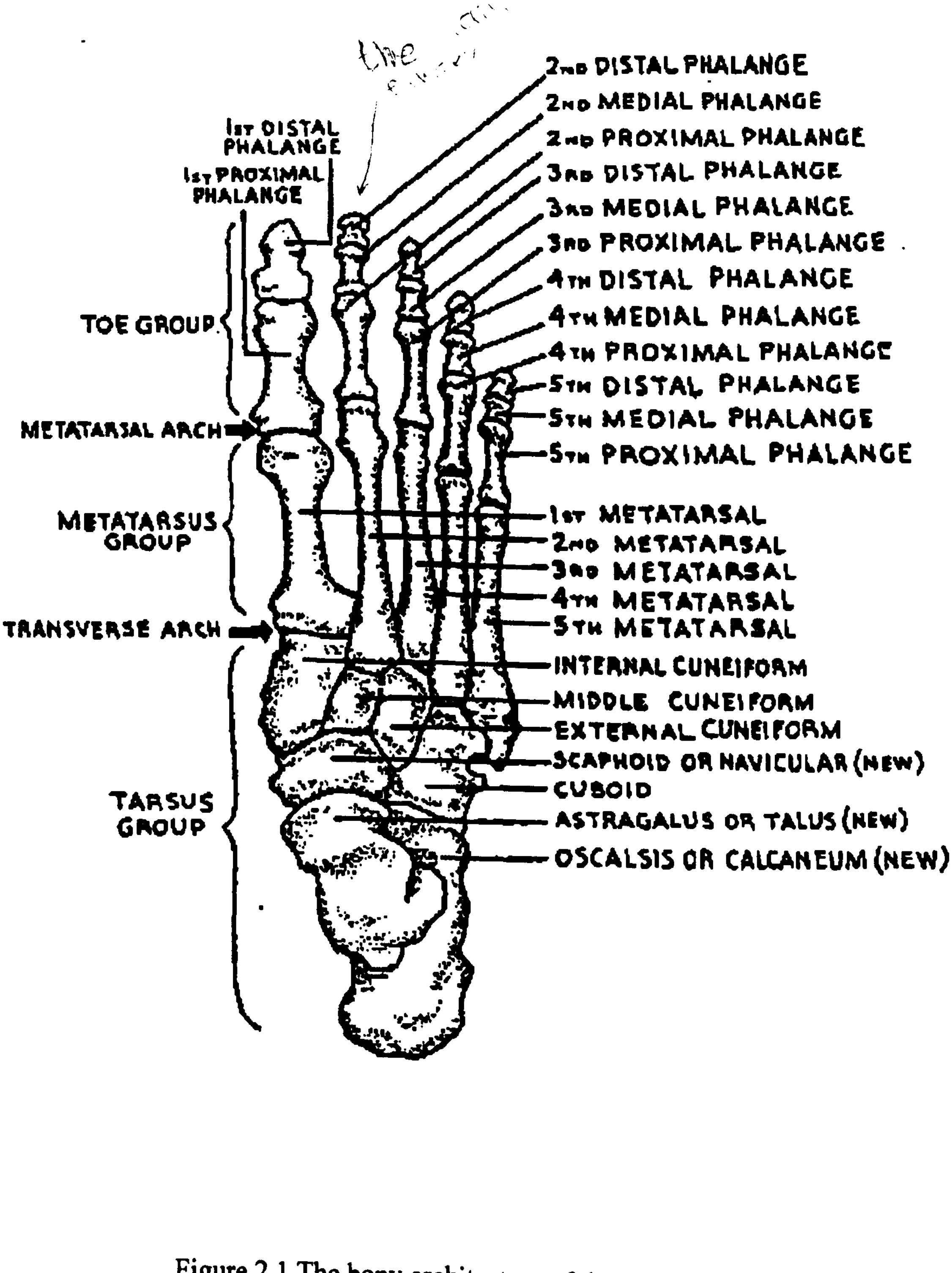


Figure 2.1 The bony architecture of the human foot

Between the metatarsus and phalanxes groups is an arch known as the anterior or metatarsal arch, and between the metatarsus and tarsus groups lies the transverse arch. The joint between the metatarsals and phalanxes (ball joint) is the position at which the foot flexes on toe-off. The first and the fifth metatarsal heads are the inner and outer ball points that are of great importance when measuring the foot and fitting the shoe for proper heel-to-ball length.

Under the head of the first metatarsal bone in each foot is a sesamoid bone which is enclosed in a tendon. Sesamoids present vary in size at different places and they are not counted in the 26 bones. These bones are strongly held together by fibrous tissues called ligaments.

- ***The Rearfoot***

The rearfoot is made up of 7 bones: 3 cuneiforms, scaphoid or navicular, cuboid, astragalus or talus and oscalcis or calcaneum. These are tightly bound by ligaments; this is also the critical position of the medial and lateral longitudinal arches (the inner and outer long arches).The arched structure of the foot contributes primarily as a shock-absorber in standing, walking, running, etc.The elasticity of the ligaments returns the arch to its original shape after deformation (QUIMBY, 1946).

ARCHES OF THE FOOT

The foot is arched longitudinally on the inside and outside and transversely at either end of the metatarsals (Fig. 2.1).

- ***Inner Longitudinal Arch***

From the oscalcis to the heads of the 1st three metatarsals including the scaphoid and cuneiforms. This arch has flexibility and provides for shock absorption and propulsion.

- ***Outer Longitudinal Arch***

From the oscalcis to the heads of the 4th and 5th metatarsals including the cuboid.This arch is nearly flat and lacks mobility and is united for its function of supporting weight.

- ***Transverse Arch***

Interdependent with the inner longitudinal arch it forms the cross-section across both the feet through the base of the 5th metatarsal, the cuboid and the cuneiforms. It is more rigid than the inner
longitudinal arch and protects the main blood vessels and nerves supplying the sole.

- ***Metatarsal Arch***

Only apparent when there is no weight on the forepart. This arch is formed across the heads of the five metatarsals. The arch provides the elasticity as well as the spring for the foot. The strong ligaments joining them prevent the arch spreading too much and a disproportionate amount of pressure going on to the middle metatarsal heads when the foot bears the weight of the body (MANUAL OF SHOEMAKING, 1976).

Good-fitting shoe construction should provide correct supporting for all arches of the foot.

2.1.1 Types of Feet

In shape and size, feet have an extreme variance. No two pairs of feet are alike and the right and left feet of a pair are seldom exactly equal. A great variation even exists between people in the same locality and doing the same type of work. People with different occupations develop their muscles differently, and the type of footwear worn affects the development of the foot. This is especially true for the flat and high arched foot. The bony structure of the foot also differs according to hereditary reasons.

The next factor of feet classification might be various placement of distal and proximal parts of the foot in relation to each other in two planes: transverse (front) and longitudinal (saggital). According to these, feet are divided into straight, turned inwards or outwards, supinated or pronated (rolled or tipped outwards or inwards at the outer or inner ankle joints) that makes additional complexity at the last design stage. As well as this, there are various pathologies to be paid additional attention to by shoe-fitters.

By reason of the fact that no two feet are exactly alike, one can readily appreciate the necessity for making shoes on individually designed lasts. However large-scale manufacturers make footwear for an average foot, thus reducing the amount of people satisfied with the shoe fitting and subsequently has an effect on overall shoe sales for a particular design.

2.1.2 Functional Anatomy

Biomechanics is the study of the forces occurring on and within the body which brings about human movement. How the foot itself twists, flexes and stretches during the support phase is highly complex and important for last designing.

Functions of the Feet

Anatomical features of the foot construction allow it to combine three main functions of springing, balancing and propelling. The springing function is the ability of the foot to preserve the arched form under the action of a load while standing and shock absorption while walking, and the larger the force the more the foot resists. Frequently with foot deformities its springing function is infringed, the foot loses its arched form, i.e. becomes flattened in longitudinal or transverse directions.

The balancing function of the foot involves its participation in supporting the balance, and consequently the vertical position of a body at walking. The fulfillment of this function is closely connected to opportunities of pronating and supinating movements of the foot while standing and moving.

The propelling function of the foot is connected to supplying acceleration to the body in walking. It occurs at interaction of the foot with the ground. The bigger the reduction of the foot support surface area the bigger the infringement of the function (GORELOVA, ARZHANNIKOVA, IVANOV, and others, 1996).

During standing, the foot is mainly supported at three points: the calcaneus and the distal bases of the first and fifth metatarsals (Fig. 2.2).

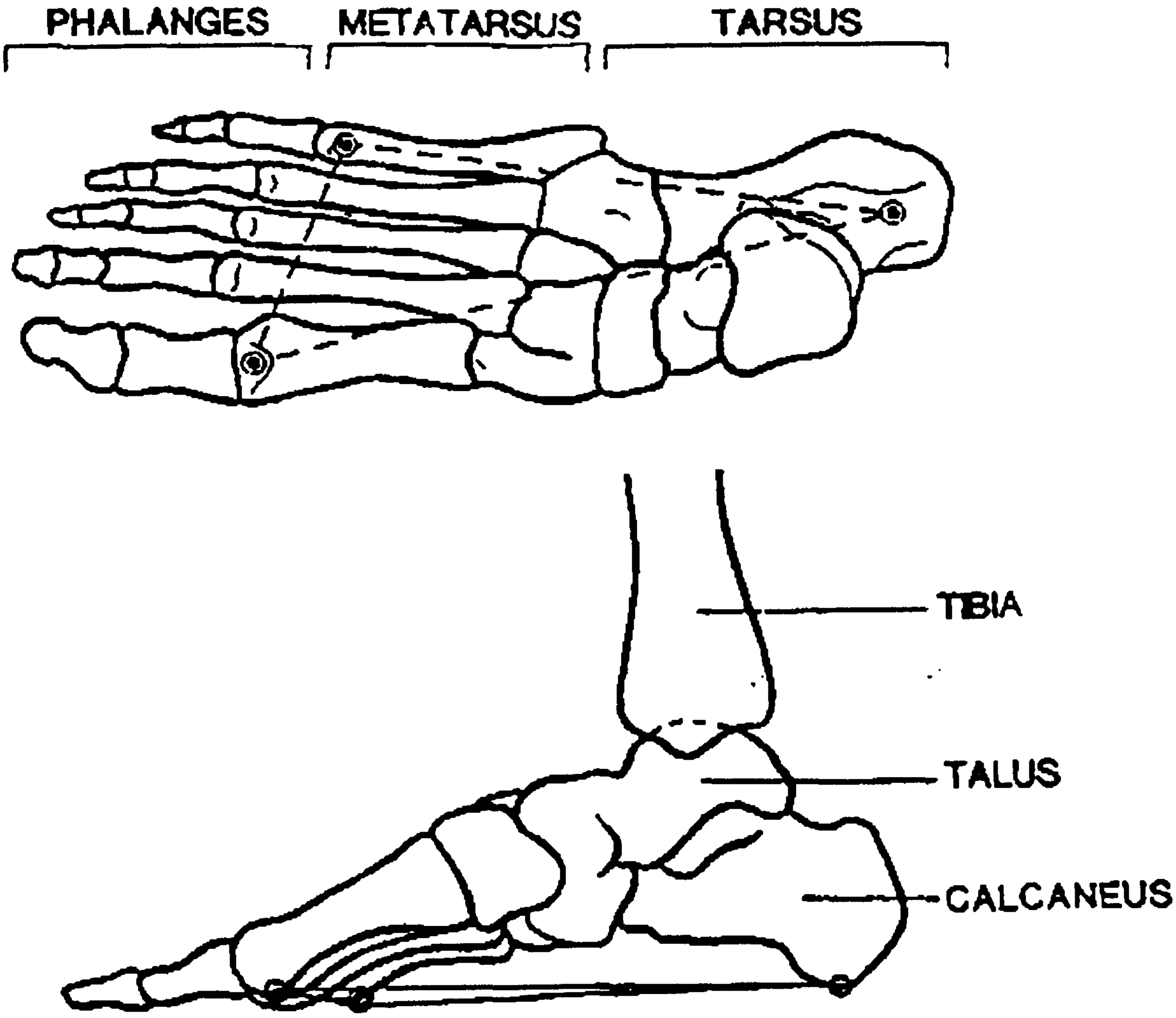


Fig. 2.2 The foot support points: the calcaneus and the distal bases of the first and fifth metatarsals

If the person stands symmetrically, the weight of his body is distributed in regular intervals on both feet. Thus, the backpart supports about 60 % of the body weight, and the forepart about 40%, and in forward department the most loaded is the first metatarsal head. This load by weight onto the foot increases its length by up to 2-3 mm, as well as the foot girth in the ball joint by up to 7-9 mm (GORELOVA et al, 1996).

Normal human walking and running can be defined as locomotion of the two legs alternately to provide both support and propulsion. When walking, almost all the muscles of the human body are active, but the main load is on the pelvis system and legs. Walking of the person is characterized by alternating periods of support by each foot, which are repeated through equal periods of time.

The walk of people of different age-gender groups is distinguished by their own features. So, a women's walk is noted for ease and gracefulness as a result of reducing the structure of their step at the time of the supporting stage on the whole foot sole and faster re-rolling through the forepart.

The later process of a women's walk basically goes in the following sequence: the heel → the head of 1st metatarsal → toes → the head of 5th metatarsal ("valgus" gait type), and at men's walking after the heel is the head of the 5th metatarsal, toes, and then head of the 1st metatarsal ("varus" gait type).

Small children emerge with their own type of gait with practically simultaneous inclusion into a support of almost all points of the sole surface of the foot.

Running differs from walking in that the foot pushes backwards and repels from the ground stronger, and then does a wide wave movement, strengthening the action of the back push of the second foot. When running both feet never touch the ground simultaneously and there are moments when neither does. They are named 'flight phases'.

When the weight of the foot is borne by the feet it is distributed from the astragalus to the oscalcis at the heel, heads of the metatarsals in the forepart and along the outer longitudinal arch. The inner longitudinal and metatarsal arches become lower and longer. This results in the foot increasing in length from the heel to the metatarso-phalangeal joint and in the joint width becoming wider. The seat also becomes wider, the joint girth increases slightly and the toes lengthen as the great toes assist in providing balance.

The seat is at its widest when the foot is lifted at the ankle joint as it leaves the ground and swings forward, but its narrowest when the calf muscles force the foot down in relation to the leg, lifting the body onto the forepart and when the metatarso-phalangeal joint allows the toes to bend up as the heel is raised and then flexes them down as the foot leaves the ground.

The foot is lengthened when standing on the ground and when beginning to leave the ground as the longitudinal arches are flattened and the outer one takes some of the weight, but in the next stage the inner longitudinal arch is heightened and shortened as the muscles tighten and it is used as a lever to lift the body from the fulcrum of the tread at the metatarso-phalangeal joint and the big toe in the last stage of the step (MANUAL OF SHOEMAKING, 1976).

All the changes of the foot dimensions during the movements should be consideredd during last design.

2.2 Foot Health

Most people would agree that uncomfortable shoes can reduce their wearer's pleasure in life more than any other item of their clothing. They can also have serious indirect effects on general health. This is especially true for elderly people whose health and happiness depend so much on the ability of their feet to get their owners out and about; and disabled people, whose problem feet are an important factor in turning their disability into a handicap.

2.2.1 Common Foot Problems Caused by Footwear

The shoe fitters must take into consideration the causes of problems as foot deformities and lesions can affect shoe fit. Most of the babies born possess perfect feet and the deformities arise as they grow mostly because of ill-fitting footwear.

Usually it takes about twenty years to fully grow a foot. The relative proportions of the different parts of a child's foot are not the same as those of the adult, and between the infant and the adult stage the proportions are continually changing. For example, when a child first begins to walk the feet are usually quite flat, the arches are not yet developed, but as the child grows, these arches develop naturally.

Or sometimes the longitudinal arch is obscured by the juvenile fat pad in the sole of the foot, the presence of which makes the foot appear much lower than it is really. The toes of a child lie straight forward in the direction of the length of the foot. The difference in length between the toes is not so apparent, thus the toes are squarer in shape. The seat of a child's foot is narrower in relation to the tread than in the adult. During development the grows in length much more than in girth; thus, the joint girth is greater in proportion to the length than in an adult foot.

The deformities arising in children's feet can be eliminated if traced early enough. The time to begin care of feet is when the tiny bones are forming and the little muscles are developing. It is during this period that the child's feet must be carefully watched and guarded. During this time the bony structure, soft and incomplete as it is, can be bent and warped and misshapen and the feet deformed and made weak. If the child is not overweight or undernourished, the feet develop naturally unless they are subjected to undue strain in walking, are hindered by ill-fitting or too small shoes (GOLDING, 1935).

Nearly all of the foot defects among children can be traced to short shoes, narrow shoes, shoes that have been outgrown and shoes which are too stiff for tender feet or which have been worn so long that they have lost their proper shape.

When designing lasts for shoes to children's feet, certain rules should be observed, such as providing shoes that are longer than the foot and wide enough so that all toes can wiggle when the child is standing with full weight on the feet. Such shoes should be made with flexible soles that bend freely at the ball of the foot where the foot bends. The ball of the foot is that area across the front where the toes bend in walking. It is natural hinge and should be permitted to function freely. For this reason flexible soles are advisable.

It is established, that foot deformities in adult feet occur more often in the case of women, rather than men (*3:1*). Specific weight of deformed feet and the degree of deformity are increased with the age: for example, women till 24 years have up to ***51%*** foot deformities, till 40 years - ***63%***, and in the age of more than 50 years - ***80%*** (GORELOVA et al, 1996).

The deformities and defects of the feet differ greatly. As mentioned above, they are displayed as a change in the foot part relative to one another in the transverse and longitudinal plane.

To change the foot arrangement relative transverse plane concern redundant foot bending (**aqvinus**), redundant unbending (**"heel foot"**), as well as changing the height of the longitudinal arches (**flat and hollow feet**). The deviations of the foot in relation to the longitudinal plane may be divided into turning inwards and outwards, as well as into pronation and supination. A combination of supination with turning inwards is termed **foot varus**, and combining pronation with turning outwards is termed **foot valgus** (GORELOVA et al, 1996).

Owing to their occurrence they can be divided into inherent and assumed. For example, the latter develops owing to wearing footwear, mainly, with narrow toes or too free a back part. Too narrow toes in footwear produce a flat foot, as in this case supporting the calcaneus in the necessary position is hindered. It is known, that wearing footwear with too high heels results in displacement of weight of a body to a forepart of the foot, in overwork, reducing and, at last, in the discontinuance of functions of the short muscles of the foot, first of all, in its ball joint area. A consequence of the foot muscles reducing is infringement of its normal condition and deformities (HOLEVA and KASHUBA, 1981).

Also the reasons for occurence of foot deformities may conditionally be divided into external and internal. The external reasons are transshipments depending on the character of work and unrational footwear, the internal ones are hereditary - structural diathesis, but also primary weakness of muscle apparatus.

In classification of the foot pathology conditions owing to an excessive static load deformities and functional handycaps are usually encountered. Static deformities concern: **longitudinal** and **transverse platypodia, hallus valgus, digitus malleus, callosities, corns and chafes.** The functional handycaps of the foot features fast leg exhaustion, painfulness of the foot and shank, oedemas of soft foot tissues, instability of joints under load, strenghthened diaphoresis (MAKAROVA, 1987).

Considerable distribution of foot deformities reduces capacity for work of the people. The preventive maintenance and treatment of the deformities have large significance. In order to prevent occurrence of deformities one has to wear the footwear of rational designs and to use prosthetic appliances. Their purpose is to prevent the feet and toes progressing to deformities, to reduce the overwork of muscles and ligaments or to protect painful sites of the feet. The prosthetic appliances are simple and could be made easily in bulk production or individually. They are in addition to ordinary footwear (KOCHETKOVA and KLUCHNIKOVA, 1991).

However the occurring foot deformities related to ill-fitting footwear is very complex and is still a current problem to solve; all of these must be taken into consideration when designing the proper last shape.

DAMAGE TO THE SKIN

When the skin is under pressure or mechanical stress there may develop a **blister, callous, corn** or **bursa**. The friction and pressure over the toe joint causes corns. This could happen directly from tight footwear which gives rise to hard corns or indirectly when toes are squashed together causing a soft corn. Shoes that are too loose, allowing the foot to slide about in them, might cause corns equally easily. A shoe too loose in the back region, and which, therefore, allows the foot to slide forwards and backwards lengthwise, can produce corns on the bottom of the foot; therefore, when fitting, the back part of the shoe should be selected to prevent the foot sliding forward during wear.

Friction also can cause **blisters** as the outer layer is loosened and the fluid is formed below it. If this continues and the blisters break, the fluid released leaves a sore and inflamed area. The heel slipping inside the shoe is a common cause of heel blisters.

A **callous** is the build up of the outer layer of skin which becomes hard. This is caused by intermittent pressure, often around the edge of the insole at the seat. If it becomes severe the pressure should be removed by replacing the footwear and removing the outer layers of skin.

The callous may occur when structure and functions of the foot are changed, also when developing transverse platypodia and one with turning the foot in the horizontal plane. Sometimes callouses may be the first sign of very serious changes in the foot shape and functions.

A **bursae** is a fluid containing sac that develops over a bony prominence to protect the area. Bursae naturally occur in certain positions, e.g. between the Achilles tendon and the oscalcis, but when they occur as a result of footwear pressure, e.g. over the big toe joint or the little toe, they are called **bunions**. Once the pressure has been removed, which in the case of the big toe joint may involve surgery as well as new footwear, the bursa can be incised.

Lesions occur when the skin becomes hard as the outer layer skin thickens even though there is no clear boundary line. Intermittent pressure causes pain and burning sensation under pressure. Although it occurs on the sole of the foot and the periphery of heel, it is usually caused by the pressure of the skin pulling down on the edge of the insole. This could be helped if the shoe fitters provide enough room to prevent pressure over and above that caused by normal movement.

Treatment of the above deformities can not achieve a stable result if are not eliminated the causes that initiated their appearance. First of all, it is necessary to apply correction of the longitudinal and transverse arches of the foot, to unload the heads of the metatarsals and the plantar surface of the toes. Of great importance is wearing the footwear which is suitable for the particular foot.

When damages to the skin are not connected with hard deformities one may wear bulk produced shoes but with particular properties: such footwear should have a heel providing physiological distribution of body weight; should correspond to the foot in width; have flexible but thick enough sole; high and hard toe puff preventing damaged toes; lengthened from the medial side stiffener increasing the bearing feature of the metatarsus; flexible and permeable insole with moulded recesses for 2nd and 3rd heads of the metatarsals. The footwear should be light (CHENTSOVA, 1974).

TROUBLES OF THE TOES

Nowadays it is generally agreed that the foot health is dependent on toe health - that is on toes which are healthy and can and do function properly.

Most of the deformities of the toes described below are caused by footwear that has insufficient space at the end and sides of the latters to allow for their extension during growth or when weight is borne by the foot or by footwear that does not hold the heel firmly in the seat but allows the foot to slide forwards.

Hallux Valgus is the deflection of the big toe against others at the 1st metatarso-phalangeal joint. Usually additional enlargement can be found of the bones or by the formation of a bursae. It becomes worse when the big toe muscle shortens and pulls the toe further. There are some extreme cases where the first metatarsal deflects away from the others either by overlapping or by underlying the second toe. A bunion forms over the metatarsal head when the big toe separates.

Although it could be hereditary but very often it is influenced by fit, the Hallux Valgus happens when wearing high-heeled shoes or with very narrow toes. Also excess pressure of footwear on the big toe affects adversely it particularly when the foot leaves the ground (HOLEVA et al, 1981).

Shoes should not be too narrow or too short as this can squash the toes. When the sign of Hallux Valgus is noticed, ensure there is enough space in order to provide space for the big toe to return to its position so there will be no pressure on it. For adult feet, there is a possibility for correction but further damage and discomfort can be prevented by careful fitting (Fig. 2.3).

Hallux Rigidus causes limited movement at the big toe joint which makes normal gait impossible. The symptoms can be traced if there is a badly worn area under the big toe tip and an absence of wear under the big toe joint. Usually a crease is across the upper toe and usually the shoe sole is badly worn because of trying to avoid standing on the big toe.

There are some cases where the toe is flexed downwards as an effect of continued pressure on the big toe when the shoe is too short.

There are some well defined abnormalities with toes which are caused by the ill-fitting footwear such as **hammer toe** (the first phalanx is extended and the second flexed

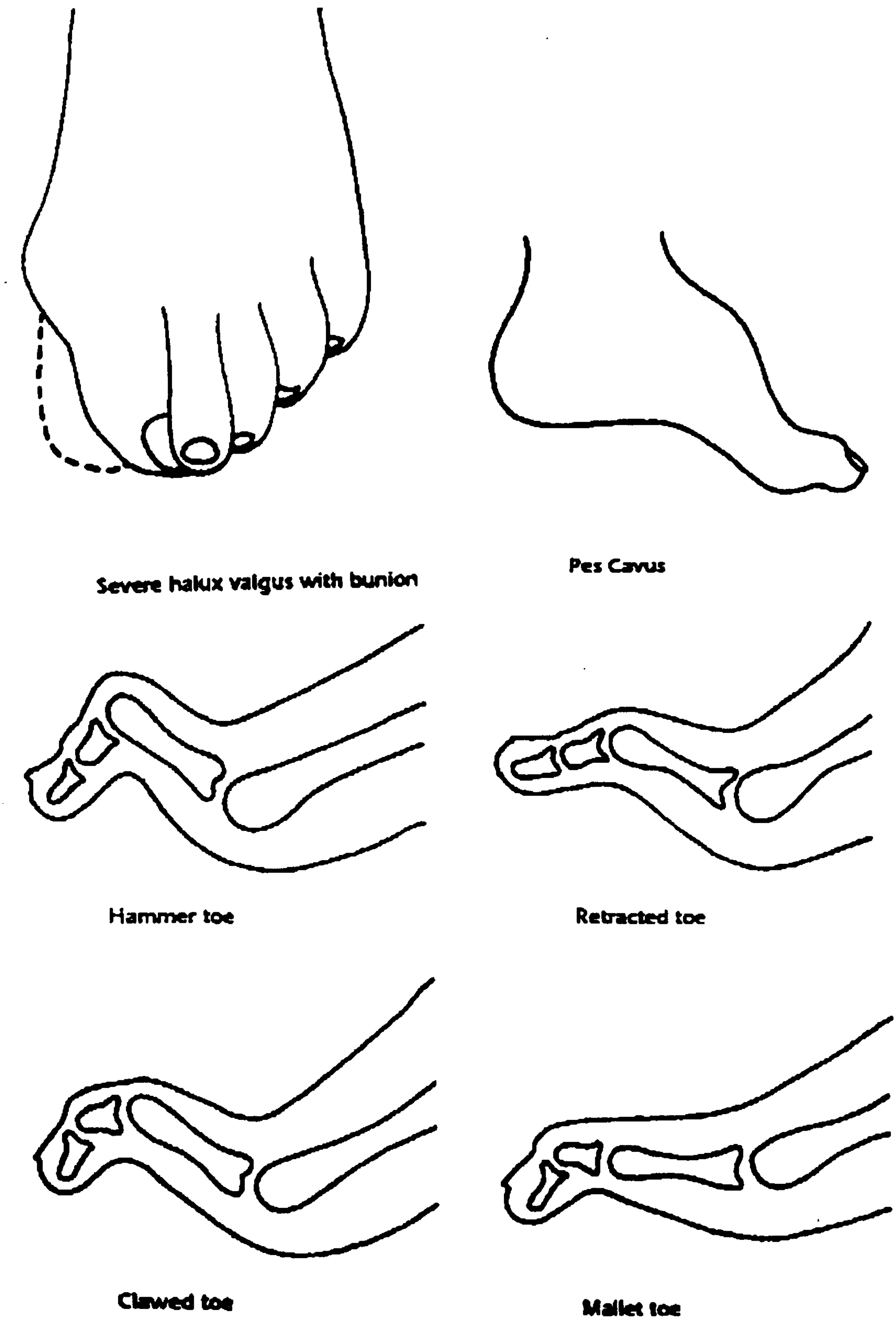


Fig. 2.3 Troubles of the toes

down; a corn often forms on the first inter-phalangeal joint), **clawed toe** (as with hammer toe but the third phalanx is also flexed), **mallet toe** (only the second joint is affected and the distal phalanx flexed) and **retracted toe** (MANUAL OF SHOEMAKING, 1976) (Fig. 2.3).

Unguis incarnatus is a deformity of the toes, more commonly the big toe. It consists of slope of side edges of nails and their ingrowing. Again the main reason of Unguis incarnatus is ill-fitting footwear (with narrow toes and on high heels) (HOLEVA, A. et al, 1981).

TROUBLES OF THE ARCHES

Platypodia is a version of foot deformities with static insufficiency. The reason for developing static insufficiency of the feet is discrepancy between the force of the supporting apparatus and the load on the foot. It leads to foot flattening in longitudinal and transverse directions (GORELOVA et al, 1996).

Platypodia could be hereditary or acquired. The latter is more often the case and happens when the foot is overloaded as it depends on weakening muscles and ligaments of the foot. Another common reason for women's flatfoot is wearing bed fitting footwear on high heels. It is impossible to recover the flatfoot, but to prevent the deformity progressing is of great necessity. Correctly designed footwear supporting the foot arch prevents the development of platypodia (HOLEVA, A. et al, 1981).

Types of Platopodia

- ***Metatarsalgia***

Pain under the metatarsal heads may be caused by dropping the heads of the centre of metatarsus. This is often caused by an overloading of the phalangxes, e.g. wearing higher heels than one is accustomed to, operating a car with a foot pedal badly positioned or wearing narrow shoes lead to cramping the metatarsal heads. A callous may be formed beneath the central metatarsal heads, thus increasing the pressure. Metatarsal pads can be fitted in the shoes, either to provide a cushion under the central metatarsal heads or to take the weight on the shafts behind the central ones.

- *Pes planus (flat foot)*

The foot's back bone tips forward causing the arch to disappear and the forefoot to rotate out. Without an arch the shock absorption properties decrease and causes discomfort. Soft, resilient soles and heels can help this by relieving the discomfort as the arched foot extends more than a flat foot.

- *Pes cavus (humped foot)*

This happens when the high arch on the inside of the foot extends through the outer border. The foot looks humped as the bones in the midregion are prominent and this causes callouses under the ball of the foot. Sometimes smaller toes are clawed and the big one flexed up-wards. The minimum requirement to keep the shoes comfortable is to have shoes with a high waist and generous instep measurement (MANUAL OF SHOEMAKING, 1976). To get rid of the foot deformities the causative factor must be eliminated, i.e. correctly fitting footwear must be worn, etc.

- *Ankle Valgus and Pronation*

This happens when the foot rotates and leans inwards so the weight is not distributed equally. This causes the weight to fall on the inner side of the foot and flattens the arch. The weight distribution becomes worse if the foot is more twisted. The defect may be corrected for babies but it may need support of the 'valgus' insole. As it is wedged, thicker on the inside than the outside, the treatment should not be used without professional advice. Although valgus causes distortion and leads to a variation of gait, it is not painful (MANUAL OF SHOEMAKING, 1976).

2.2.2 Ill-Fitting Footwear Affected by Inadequate Last Design and Factors Affecting Foot Comfort

As mentioned above, most babies are born with perfect or near perfect feet. For them the majority of foot troubles are cased by ill-fitting footwear or socks. If noticed early enough, many of these troubles will correct themselves if better fitting clothing is worn. Unrestricted last designing, as well as the unrational design of footwear may be one of the main reasons for shoe discomfort, its deformations and development the foot pathologies. Besides, inadequate last designing does not meet requirements presented by footwear technology and related manufacturing that supply the shoe industry with moulded parts and shoe machines.

Researches of lasts manufactured in Russia have revealed a number of defects in their construction. For example, there are lasts whose bottom profile has a sharp bend in the shank part inappropriate to the character of this part of the foot; or lasts which bottom profile promotes moving the foot ahead; there are also lasts with insufficient height of toe spring in the section of the big toe (sharp flattening of the toe part).

Other last defects are also excessive pointing of the toes, promoting toe deformities and infringing normal circulation; sharp curving of the last bottom (in a horizontal plane) caused by wrong relative arrangement of the medial and lateral feather edges; sharp narrowing of the last bottom in the basic sections; flat contour of the last bottom and etc. Besides, when manufacturing the last, the feet age features are not always taken into account (CHENTSOVA, 1971).

Transient states from the foot to the last should be finished off step by step with considering changes of foot shape and sizes while working, safe pressure on foot by the footwear in various anatomical sites not disturbing conditions which are necessary for normal foot functioning. When designing the predetermined shape and sizes of the last could be changed according to the features of construction and closing method of the footwear and special requirements related to tooling-up designing (CHENTSOVA, K.I., 1971). However, these amendments should not infringe medical-orthopaedic requirements.

Of particular difficulty is developing a rational last bottom profile and its back part shape as even people within a narrow age-gender group have large differences in back part shapes and height of the arches (MAKAROVA, 1987).

Practice shows that irrespective of even a very well designed shape of the last back part it can not be uniformly suitable for upright and clearly arched back parts of feet. But if in this case elastoplastic properties of stiffeners and upper designs could in certain limits provide breaking in the footwear to various back part shapes, but adjusting the shank part of the footwear to high, low or flattened in a various degree foot arches presents very large difficulty (CHENTSOVA, 1971).

Very often it is impossible to recover foot pathologies but to prevent the deformity progressing is of great necessity. The development of preventive measures is basically directed on reduction of loading of the muscle-ligament apparatus, muscle development and more rational use of the apparatus (HOLEVA et al, 1981).

All types of preventive footwear developed or produced in a number of countries corresponding to a way of its effect on the foot can be divided into four main groups:

1. Passive effect by various prosthetic appliances, the purpose of which is to support the foot in a certain position (for example, stiffeners and insoles of special design, providing the correct heel position) is peculiar to the first group;
2. Active effect promoting the foot twisting (increasing the arch elasticity) is characteristic of the second group;
3. For the third group the effect on the foot by mechanical irritants located on the basic surface, activating work of muscles, is characteristic;
4. Influence by soft elastic channel (insoles of foam plastic or felt) in the footwear on the foot, to control conditions for work of all leg muscles, is characteristic to the fourth group.

Preventive laying out should be determined from the physiological point of view, i.e. its height should be such that to held the foot arches only when muscles are very tired and the arch begins to drop down.

Also a preventive sock eliminates redundant moisture (perspiration) by wicking intermittently. To hold the heel in a straight position when it is deflecting sharply one should use stiffeners with "long wings" (whose length depends on the shoe style) and insoles with raised rigid edges in the form of slot.

It is suggested to provide preventive footwear with a curvature of 5 mm under 2^{nd}-5^{th} metatarsal heads for unloading the middle heads. The highest curvature should be under

3rd metatarsal head. The width and length of the heel should be close to 1/4 of sole length.

As flattening the foot begins from childhood they recommend to establish the following parameters when designing children's preventive footwear:

- heel height - 1/14 of the foot length;
- height of preventive laying out - 3-5 mm depending on the child's age;
- length of stiffener wings - till 1/2 length of metatarsals;
- bottom axis should run through the heel centre and between the second and the third toes (CHENTSOVA, 1974).

However, because of insufficient knowledge about the reasons and mechanisms for developing the large variety of foot deformities, preventive methods and means used are characterized by great diversity. Therefore, to generalize, all these methods and to develop an appropriate system are of great difficulty as they are based on different approaches.

Obviously, for modern manufacturing conditions it is necessary to reveal laws of foot deformities occurrence and, on the basis of data obtained, to develop comfortable lasts and footwear designs.

2.3 The History of the Shoe Last

The origins of footwear and when the first shoes were made are unknown. Before footwear as we know it today developed, men protected their feet using the skins of slaughtered animals which were wrapped around their feet. Hence, it can be said that the foot itself was the first 'last'. There is no accurate statement about when people created the last.

No one knows the actual date when the first lasts were made. It could be ten thousand years ago or even much earlier. It is proved from recorded evidence that the date of men using lasts goes back at least some two thousand five hundred years. During the fifth century B.C., the Greek sculptor Apelles told the shoe maker to “stick to your last“ and it was recorded as the first mention of lasts. Moreover, in the first century B.C. a wall painting in the city of Herculaneum shows a shoe maker removing a last from a shoe. The other example is in the first century A.D. where Pliny the Elder mentioned about the shoe maker and his last.

The first recorded shoe craftsman was Thomas Beard who arrived in Salem, Massachusetts in 1629. It is stated in the old journal of Salem that Beard "whittled his lasts from maple or the hard wood with a spoke shave and drawknife". This is the earliest mention of last making. In Philadelphia, Pennsylvania, the first last maker recorded was William Young. He had been granted a patent for a minor last improvement in 1807.

Until the 19th century, lasts were made by hand. The lasts were made by the shoemakers themselves and there were very few in stock in the shop to suit their customers. Anyway, they did not cater for many different sizes, widths or shapes. Even though lefts and rights in lasts had been introduced in 1807 in the USA, all shoes were still made on "straight" lasts meaning no rights or lefts. In 1815, there was a remarkable change in last making. In Massachusetts, Thomas Blanchard of Sutton converted a lathe, which was originally used for making gunstocks and axes handles, into a machine for turning lasts. Blanchard was granted a patent on this on the 6th November, 1819 and this was the beginning of the last making by machine to replace hand made lasts.

In addition, in 1840, there were some improvements in last making. The variation in width was made by placing a pad or shell over the front or cone portion of the last. Also one last served for two widths. Those previously mentioned two widths were known as "fat" and "slim". During that time, lasts were made only in three sizes which were small, medium and large.

The demand was increasing by 1855 due to the prosperous shoe industry in Massachusetts which was growing rapidly and it continued to increase from 1860 to 1900. At that time, there were tremendous developments in the shoe industry where the innovation of mechanical shoe making and the introduction of many major new machines took place. Due to the great demand for lasts, there was emphasis by last factories to concentrate on productivity (quantity) instead of quality. Also, due to the added complication of grading, lasts had not been made rights and lefts. Another reason was that last making itself was very time consuming.

However, the adoption of lefts and rights in lasts had become commonly used at the end of the 19th century. It was about the same time (1887 or 1885) that the first scientific shoe sizing system was adopted by American manufacturers regardless of the system which was introduced by Edwin B. Simpson in 1880 in New York. He created the standardized last measurements for men, women, children and infants. The system is in half sizes which is measured in sixths of an inch and widths measured in quarters of an inch. Finally, the last and the sizing and fitting systems had been developed to a mature stage by the early 20th century.

2.4 Types of Last

The starting point for the design of footwear is from the last. The last is a reproduction of the approximate shape of the human foot. A properly constructed shoe, when made over this form, will furnish foot support and foot protection without undue pressure, binding or constriction at any point. The last, therefore, as the very foundation of the shoe, carries a great responsibility. Upon it depends the fitting qualities, the walking ease and the stylish appearance of the finished shoe. Because of this, the making of lasts is the most important factor in good shoemaking. In order to understand in more detail about the last, this section will cover the variety of types of last.

TYPES OF LAST

Lasts are developed on the basis of measuring the feet of a population of various age-gender groups. The last is designed to provide a comfortable internal shape to the footwear, i.e. it should correspond to the sizes and form of the foot and not hinder its normal functioning and development (GORELOVA et al, 1996).

The correct choice of lasts has great significance for reception of the rational form of the footwear in accordance with its purpose, promoting good foot fitting and adequate aesthetic requirements.

In the shoe industry each type and design of the footwear are produced on the lasts in different styles, distinguished by the toe form, heel-height and other attributes. The variety of styles facilitates fitting the footwear to better meet customers' demands.

Last Classification

Shoe lasts are classified in groups (types), numbers (sizes), fittings, heel elevations, functional purposes, designs, materials, the type of footwear (for sandals, shoes, court shoes, Oxfords, Derbies, boots etc.) and the type of footwear manufacturing process.

Main (production) lasts, used for upper lasting, are subdivided into the following types:

1. On Design:

- **Solid Block Last**. This is mainly used for chappals and sandals.
- **Scoop Block Last with cut wedge**. This is primarily used for custom shoe making or the hand-made footwear trade.
- **Hinged last**. This is an articulated or detachable last. Normally used in the machine made footwear industry for all types of shoe construction.
- **Telescopic Last**. This is mainly used for sliplasted methods of footwear construction in mechanized industry.

2. ***On Functional Purpose:***

- **Model last**

  The model last is the main key in order to produce in bulk other lasts for the production line. The technique is to use a last turning lathe and the whole range of sizes and fittings will be produced in accordance with the last model. It needs high accuracy of the model last measurements in order to provide for the various requirements of customers. It is necessary to choose a suitable material for making a model shoe last, and wood is normally used in the factory, the reason being it is easy to shape and to make alterations.

- **Production Last**

  To provide a large amount of lasts in the factory for making shoes, the production last is the common last in the lasting department. The major material used to produce this type of last is plastic (Polyethylene). In certain cases, aluminum or wood have been used. The production last has an exit device for shortening the last and for ease in slipping it from a finished lasted shoe.

- **Metal Last (Moulds)**

  In the shoe factory which produces shoes by using the injection and vulcanized system, the last should be able to stand the hot temperatures. The metal last is commonly used which are made from aluminum. This last also can stand high pressures and this is the main advantage and is relatively lightweight.

- **Pullover Last**

  Shoe designers need this type of last in order to get the desired fashion shape for display. This last is a solid wooden block without any exit device.

3. Also lasts could be classified based on the ***method used for the footwear manufacturing process*** (attaching the upper to the innersole of the footwear).

4. Any ***form of attachment*** made by clenching rivets, or by tacks, or screws, need plates on the bottom of the wooden lasts:

- **All bottom metal plated**: for machine sewn, stuck on, vulcanized shoes;
- **Half iron plate and long iron plate**: for various combination constructions and a few types of moccasin construction shoes;
- **Heel iron plated**: for welted, moccasin and slip lasted shoes;
- **No metal plate**: for veltdschoen, cement and slip lasted shoes;
- **Heel and toe plate**: for Littleway and construction of stuck-on shoes.

2.4.1 Hinging Systems and Release Devices

The forepart and backpart of a last are generally 'hinged' to enable them to be removed from the shoe after the shoemaking process is complete. The purpose is to reduce the length of the last which, in turn, releases the tension on the top-line.

There are a variety of systems available. Some feature a spring, usually "C" - shaped, which is tensioned as the last is set into its correct configuration for shoemaking. This provides the stability needed for the shoemaking process.

With some type of lasts, the tension is fully removed during the break while for others, only part of the tension is removed. Some systems, such as Speed-E-Slip, do not rely upon spring tension but use a locking device held in place by a weak spring. Not all lasts are 'hinged'. For example, the scoop block relies upon removal of the cone of the last to relieve the tension on the top-line.

The modern hinging systems fall into the following groups: link hinge, reverse cut hinge, backwardsvertical hinge Speed-E-Slip and scoop block.

Link Hinge

A link hinge consists of a 'C'-shaped spring which is held in place by two pins. The interface between the back and forepart of the last is cut to provide a pivot so that the last can be shortened to aid removal. The spring is inserted under tension and some tension is always present whether the last is broken or not. This is the most common system in the UK and North America (Fig. 2.4).

With this type of hinge, there appears to be a snap-over action which maintains the last either in the open or closed position. It is achieved by making the centres of the pins holding the spring lie just below the centre of rotation of the backpart (Fig. 2.5).

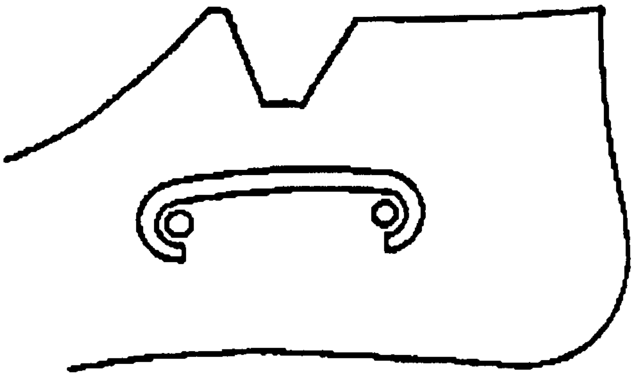


Fig. 2.4 Link hinge

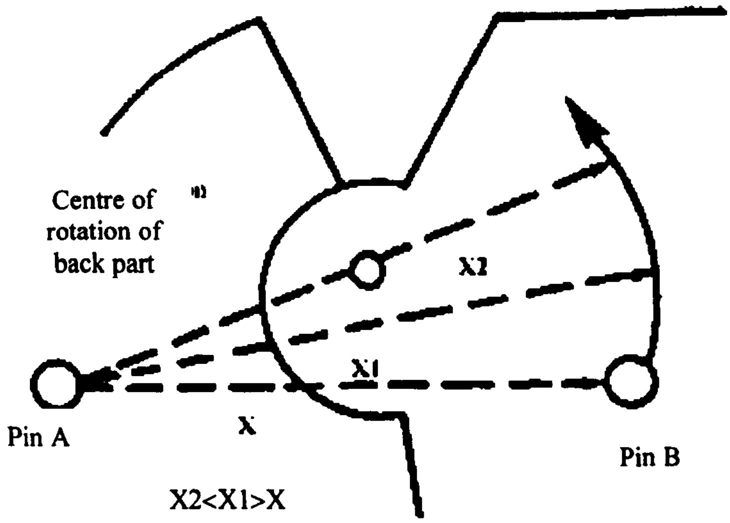


Fig. 2.5 Geometry of link hinge

Reverse Cut Hinge

The reverse cut hinge system is a little more complicated. It is, in fact, not a hinge but a system of links which hold the last firmly in the closed position and enable the last to shorten when broken. The movement of the backpart is a rotation. The mechanism consists of a link which has a hole in one end and a lot in the other and a sligtly distorted 'C' spring.

When the last is closed, the two pins holding the link are at their maximum distance apart and the hinge is under tension, locking the backpart and forepart together. At the break, the action is to move the two pins holding the link together and thus to relieve the tension on the spring (Fig. 2.6).

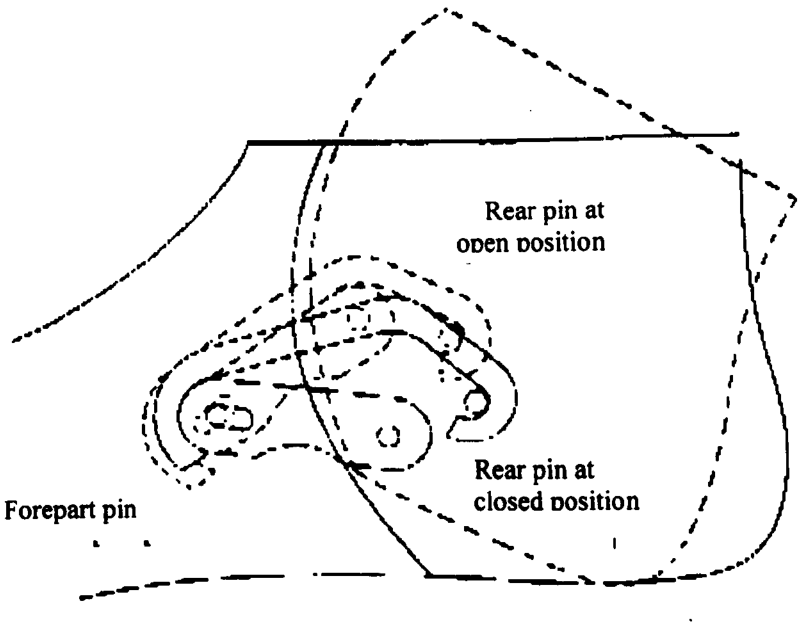


Fig. 2.6 Link system for reverse cut last

Backwards vertical hinge

This is a variant of reverse cut and is used for moulded-on work. Its main purpose is to enable shoes to be easily relasted. It has the same link mechanism as the reverse cut exept that it is arranged so that its forepart rather than its backpart rotates upwards (Fig. 2.7).

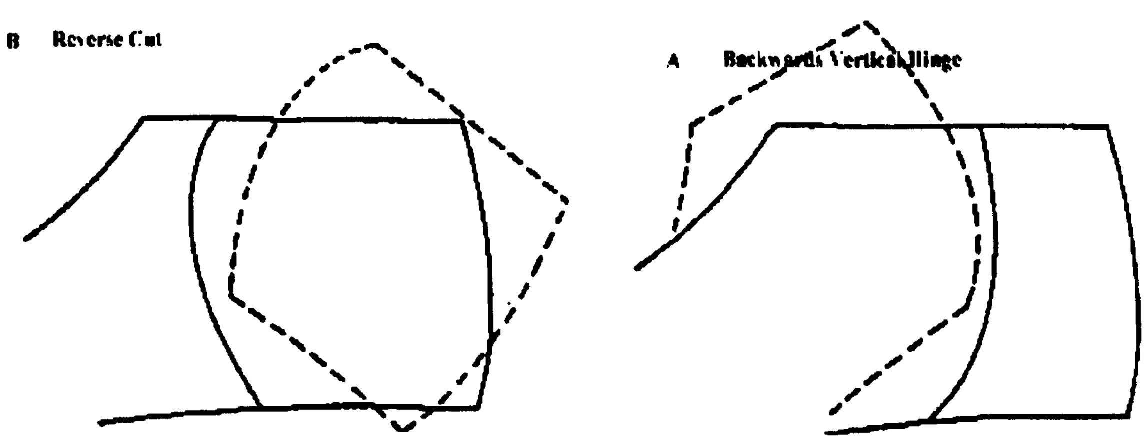


Fig. 2.7 Comparison of action of reverse cut and backwards vertical hinge

Speed-E-Slip

This type of hinge or link has the same type of action as the reverse cut. However, in breaking the last, the backpart moves directly upwards rather than rotating (as with the reverse cut). The positive lock, when closed, is achieved by the use of a weaker spring than with the other two lasts. A lever, which is slotted, hooks onto a pin and holds the last in the closed position.

The lever has an extension which has to be moved to disengage the hook from the pin. The mechanism is shown in Fig. 2.8.

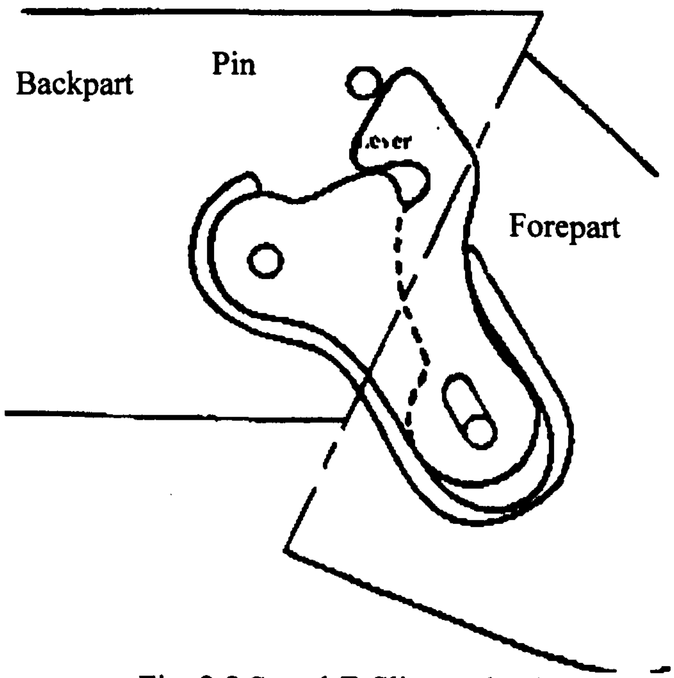


Fig. 2.8 Speed-E-Slip mechanism

Scoop block

The scoop block is neither a hinge nor a block. It consists of a section on the cone which can be removed to ease the problem of removing the last from shoe. A spring pin is included to hold the block in position (Fig. 2.9).

Because of the need for access to the release button with this type of last, it can only be used on low cut styles.

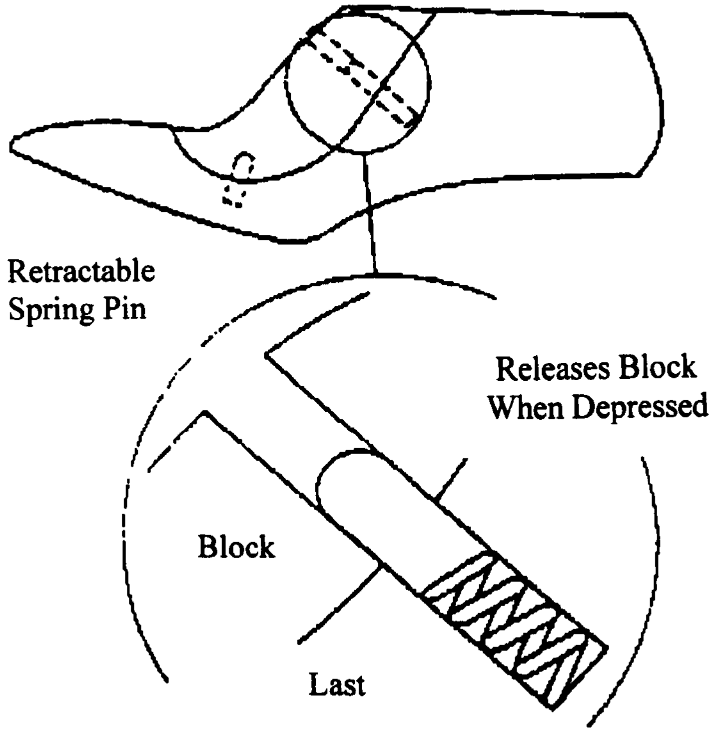


Fig. 2.9 Scoop block last

The performance of various hinging systems

Because of the shape of the back curve, the top-line tends to stretch as the last is removed as it hinges on its hinge system.

Another aggravating factor is the last swells which have to pass through the top-line. These together can impose a considerable amount of stretch on the top-line and can cause tearing. Lasts are hinged to prevent this by ensuring that the last 'shortens' to help it to pass through the top-line.

Some last break or hinge mechanisms are better than others. SATRA has carried out work on women's court shoes to study the effect of scoop block, link hinge, reverse cut and Speed-E-slip systems on top-line stretch. It revealed the following:

- Low-heeled lasts and link hinge lasts stand more chance of breaking top-lines than high-heeled lasts. This is borne out by practical experience in the factory.

- Link hinge and Speed-E-Slip lasts give little or no top-line extension. If top-line breakage is a problem, it is probably better to move to a reverse cut or Speed-E-Slip type if other means of overcoming the problem fail (LASTS, 1990).

2.4.2 Last Characteristics Related to Shoe Styles, Fashion Trends and Fittings

Although foot-shaped, a last is not an exact copy of the foot. Its shape is dictated by factors such as fit and comfort, ease of manufacture and fashion.

People expect footwear to be comfortable, well fitting, and fashionable. To ensure comfort provision must be made for the freedom of movement required by dynamic changes in foot shape. Good fitting implies a good clinging sensation on the foot, with the absence of unsightly folds when the boot or shoe is in a normal position.

To make a shoe fit the foot, changes must be made in a last from the natural form, as freedom of movement during wear must be provided by the last shape. Provision for expansion in the forepart must be greater for heavy types of footwear than for lighter types.

Also a tight clip is needed on the top-line of most shoes to help them to grip the foot and give a neat appearance. Last-makers achieve this by making the last narrower than the foot in this region. However, footwear which is too large causes blisters as the foot moves about in the shoe.

Movements of the foot cause the shoe to bend; the bending of any cylindrical object reduces its volume, consequently the internal capacity of a shoe made from firm materials must be reduced when the shoe is bent. Therefore lasts are made of different shapes and distinct types for different purposes.

The increase in length beyond the toe end of the draft is necessary to provide for the extension or moving forward of the big toe during walking. The big toe tends to turn up at the finish of a step, and the extra length conceals the thickness of the last at that point where it is needed for freedom of movement. The amount of length to be added depends on the shape of the toe required in the finished shoe.

Narrow, thin toe end appearance needs more extension in length than does a square, thick effect. Similarly, less increase is needed for high-heeled than for low-heeled shoes. In high-heeled shoes the toes crowd together, while in low-heeled shoes they spread out. It should also be noted that the toe and heel action during walking is greater for low than for high heels.

Variation from the plan of the bottom, as represented by a draft, is made for the weight of the shoe. The general outline is followed by the bottom of the last; but the side profile is wider for heavy boots, and can be made narrower for light shoes. For the latter, a reduction of 3 mm on each side is not excessive. At the waist also, changes are made for the type of shoe. There should be a wide waist for a heavy shoe, narrower for medium, and very narrow for a light or high-heeled shoe.

Also good fit is largely influenced by the type of shoe. For instance, ladies court shoes which are held on by the pressure between the foot and the shoe, must be tight, whereas shoes with laces can be more generous. These factors influence the dimensions of the last.

Shoemaking also demands special last features not found in the foot's shape. For example, to assist shoemaking the bottom of most lasts are flatter than the foot and the edge of the bottom is sharper.

Undoubtedly the biggest influence on shape and consequently on the mismatch between the foot and the shoe is fashion trends. 'Fashionable' means that the footwear conforms to a certain outline, irrespective of the natural shape of the foot.

Fashion changes are not confined only to colour, materials and upper design: footwear and, therefore, the last. It is the toe of a last which is mostly affected by change in fashion. Undoubtedly the toe imparts character essential for appearance, but it must be located correctly in relation to the general style of a last.

'Exclusive' fashion footwear calls for lasts with fine lines which are distinctive in character. Lasts such as these, however, can only be reproduced in footwear made from selected materials and constructed under certain conditions.

Utility is another condition to be satisfied, chiefly by the materials in the footwear and by the form of its construction.

Materials can also affect the last shape. For instance, stiffer, less stretchy upper materials demand a more generous last. Also, stiffer soling materials and constructions demand some longitudinal curvature to help in walking because flexing is restricted.

The value of any last depends on the shoemaker's ability to put it to the right use. A last may be perfect for a selected type of foot and form of boot construction, but if it is used for any other purpose than that for which it is intended, its fitting properties are lessened.

Since numerous styles are made from the same type of last, only the general characteristics of a particular type can be described as 'combination lasts', i.e. those suitable in general character for two or more types of footwear. For example, strap shoe designs can be made on some court shoe lasts, although courts cannot be made on a strap shoe last when attention is given to the finer points of the design.

So, it is preferable to produce different constructions on different lasts. The following notes indicate the main differences (Fig. 2.10).

Moccasins

- Sharply defined feather edge.
- Flat bottom.
- The toe end of last vertical with the cone close to the centre.
- Extra toe spring given to prevent excess vamp creasing.

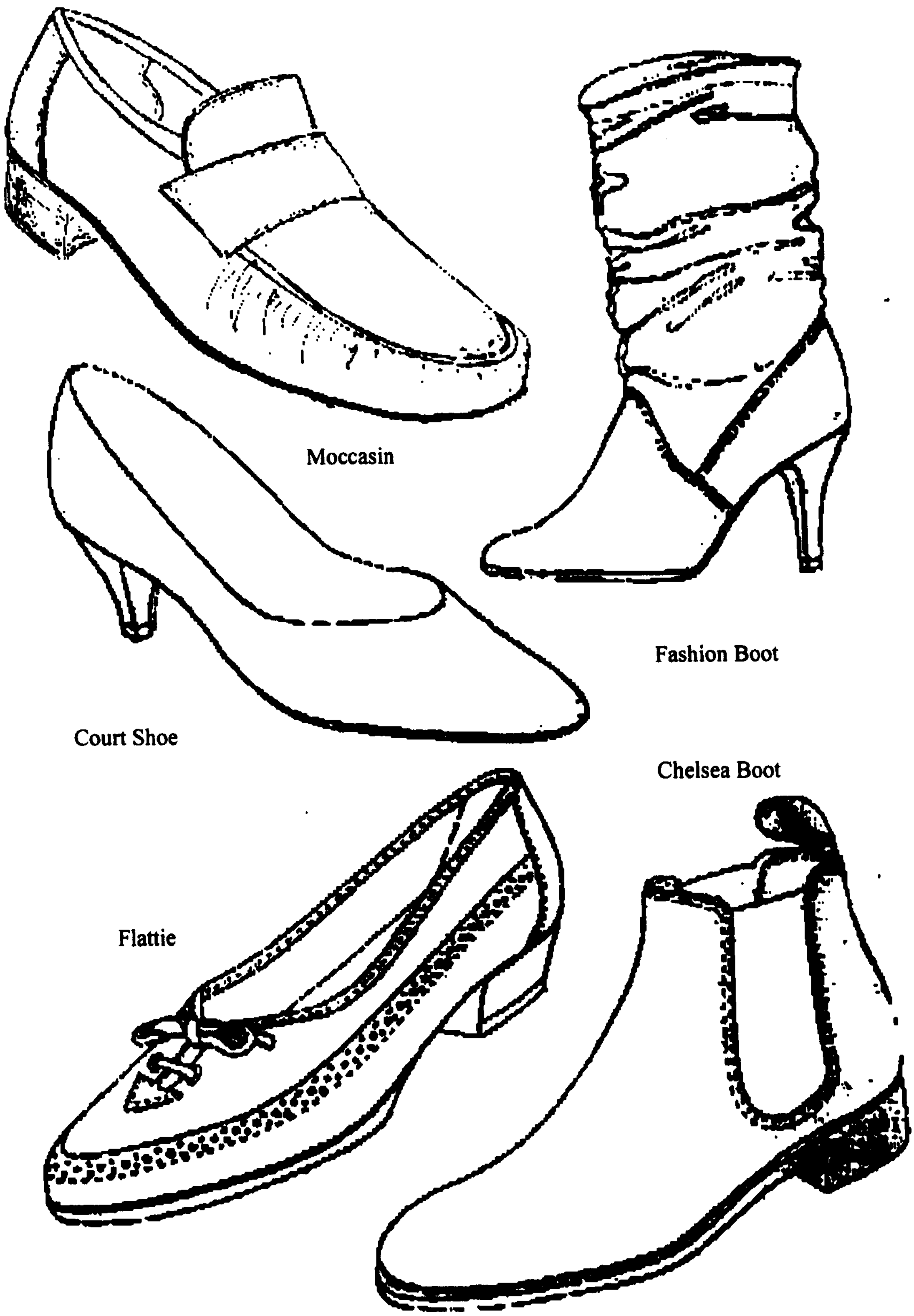


Fig. 2.10 Different types of footwear

Veldtschoen

- Bevelled feather helps in producing a sharp 90° angle on the upper where it is turned outwards.

Moulded footwear

- Where high temperatures can be a problem as with direct vulcanised work, for example, metal lasts are used. The footwear is transferred to them prior to vulcanisation.
- Metal lasts need to have a break which allows the shoes to be put on them with ease and without distortion.
- Footwear with polyurethane bottoms, which do not involve heat, can be made on polyethylene lasts. These require greater precision than that used to produce normal plastic lasts both in terms of inherent accuracy and that used to fit a gripper or holding mechanism.

Welted

- They are generally made with a difference in angle between the plane of the backpart and forepart.
- They have greater bottom curvature than conventional lasts.
- Plated in heel region to turn over seat lasting tacks and to prevent the instrusion of heel attaching pins into the shoe.

The plating on lasts was primarily intended to prevent damage to the bottom of the last and to turn over or clench lasting tacks. It is used also nowdays to reinforce the feather edge of the last.

Ladies court shoes

- They are generally made to be flat on the undersurface in both the seat and the forepart region to help in lasting. It also helps insole moulding.
- The heel feather is symmetrical to help in the fitting of heels.
- Narrower, tighter fitting last to hold shoes on the foot.

High leg footwear

- Heel curve is modelled to follow the contour of the heel and leg.

In order to satisfy all mentioned conditions the last model maker must depart from the actual form of a foot as defined by its specification and measurements.

2.4.3 Last Definitions

To make it easier to understand specific last terms the interpretation of last definitions is explained below in relation to Figures 2.11:

Ball Girth: the greatest dimension around the last, passing through the ball break. Measurement is determined by a last tape positioned to allow the tape to lay flat while tracking exactly on itself as it is wrapped continuously around the last. Waist Girth: the smallest dimension around a last between the ball girth and instep girth. Measurement is determined by last tape as described under 'Ball Girth'.

Instep Girth: the dimension around a last passing through the Instep point. Measurement is determined by the use of last tape as describe under 'Ball Girth'.

Long Heel Girth: the dimension around a last passing through the heel feather line and vamp points.

Back Cone: that portion of the cone surface between the 'V' cut and the back end of the last.

Back Cone Height: the vertical distance between the heel feather line plane and the back cone top plane.

Back Cone Top Plane: the plane of the top surface of the back cone.

Back Cone Top Plane Centreline: a line of symmetry of the back cone top plane.

Back Cone Top Plane Width: the widest dimension of the back cone top plane.

Backpart: that portion of the last extending rearward from the break of the ball to the back of the last.

Backpart Width: the width of the heel end measured parallel to the heal feather line plane at a specified distance from the heel point.

Backseam Tack Height: the vertical distance between the heel feather line plane and backseam tack.

Base Plane: that plane to which the last in its proper attitude is referenced for the purpose of defining certain terms.

Breastline: an arbitrary line defining the forward boundary of the heel seat.

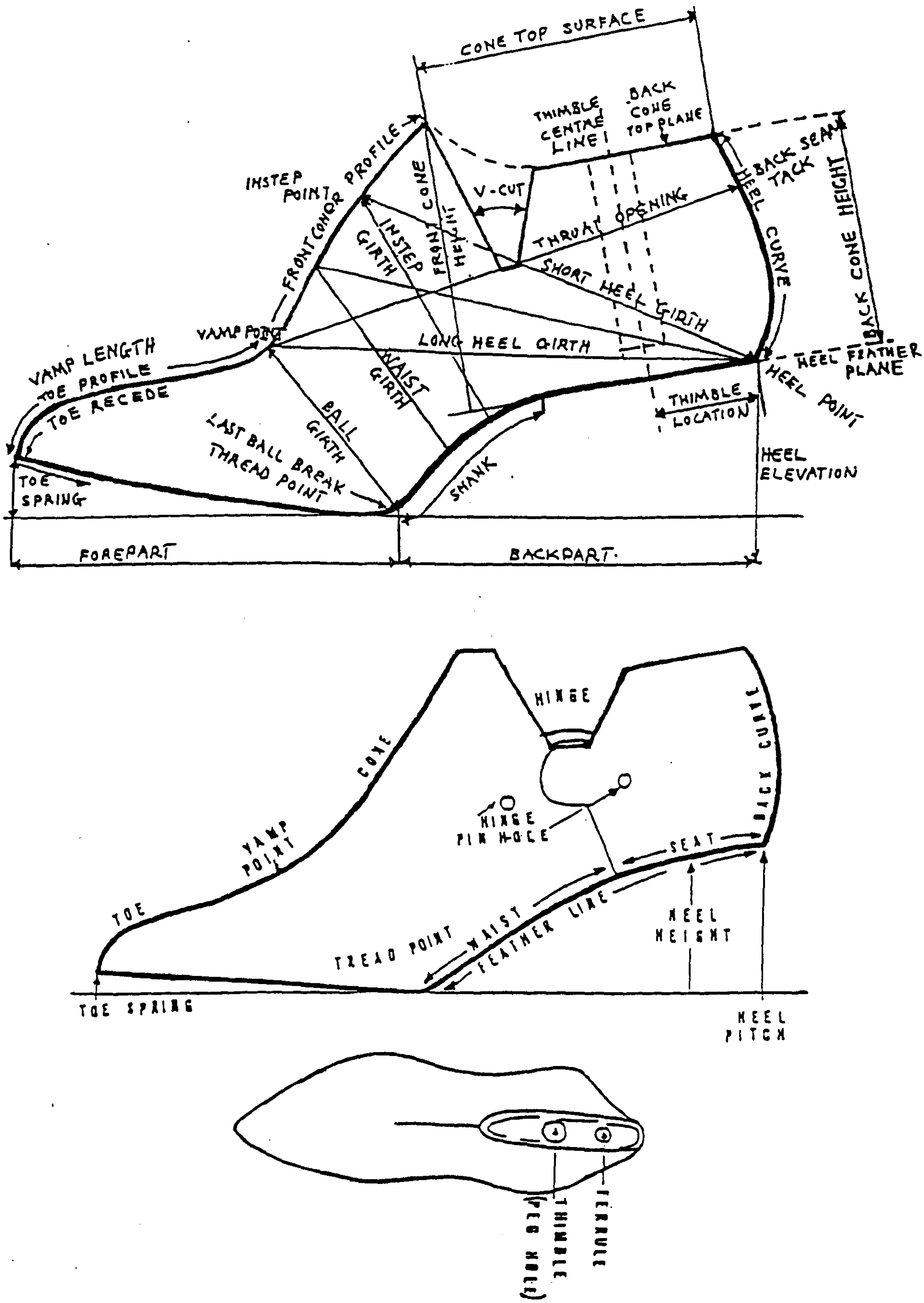


Fig. 2.11 Last Definitions

Cone Top Surface (ankle opening surface): the surface that is the back cone top plane extended to the top of the front cone.

Cone Top Surface Outline: the profile of the cone top surface as viewed from the top of the.

Cone Top Surface Profile: the profile of the cone top plane as viewed from the side of the last.

Forepart: that portion of the last extending forward from the break of the ball to toe.

Forepart Centreline: the best line of the forepart bottom pattern.

Forepart Feather Line Plane: a plane passing through the forepart feather line. In the Geometric last, the forepart feather line plane is perpendicular to the last centreline plane: therefore, having no lateral angle, or twist, with respect to the heel feather line plane.

Front Cone: that portion of cone surface between the vamp point and the 'V' cut.

Front Cone Height: the vertical distance between the projection of the heel feather line plane and the top of front cone.

Front Cone Profile: a side view profile of the front cone.

Heel Centreline: the line of best symmetry of the heel seat.

Heel Curve: a side view profile of the back end of the last from the top of the last to the heel seat feather line.

Heel Curve Angle: the angle between the heel feather line plane and a line drawn from the heel point which intersects the heel curve 2" inches up from the heel point.

Heel Elevation: with the last positioned on the base plane, vertical distance between the base plane and the heel point is the heel elevation.

Heel Feather Line: a line that defines the heel seat shape. In the Geometric last, the heel feather line plane is perpendicular to the last centreline plane and is, therefore, perpendicular to the thimble hole centreline.

Heel Feather Line Plane: the plane of heel feather line.

Heel Point: the rearmost Point of the heel feather line.

Heel Seat: the bottom surface of the heel end of the last from the breast line back.

Heel Seat Width: the greatest width of the heel seat measured from feather line to feather line, perpendicular to the heel centreline.

Instep Point: an arbitrary point established by the model maker for grading purposes. It is located at the approximate mid-point of the last on the last cone profile. The instep point references the instep girth and short heel girth.

Last Centreline Plane: a plane determined by the thimble centreline and toe point.

Short Heel Girth: the dimension around a last passing through the instep and heel feather line point.

Stick Length: the over-all length of a last as measured with a last size stick.

Toe Point: the point of intersection of the forepart centreline and bottom feather line in the forepart of the last.

Toe Profile: a side view profile of the toe end of the last.

Toe Recede: the slope of the top surface of the last, extending from the toe point to the point of full toe thickness.

Toe Spring: the vertical distance between the base plane and the toe point of last having the desired heel elevation.

Vamp Length: the distance measured along the toe profile from the vamp point to the toe point.

Vamp Point: a reference point on top of the last forepart and at the center of the last tape as it crosses the last centreline plane, when the tape is used to measure the ball girth.

2.4.4 Last Specification and Production Technique

Last making is basically simple - a model is carved and it is then used to produce a range of graded sizes using a copy lathe. However, because of the need for standards, restrictions and co-ordination, the matter is more complicated.

The process starts with the production of a hand-made master model, which is normally made of wood. Last models are not usually made from new but are oftened adapted from existing models. It represents what the end product will look like in terms of fit and shape. Its size is normally in the middle of the size range to be produced but there are no hard and fast rules governing its exact size.

The model last shapes are made by means of simple hand-cutting tools, such as toe- and heel-knives, spokeshaves, bow-saw, files, rasps, and sandpaper.

As the range turned from the master is extended, certain shape characteristics of the model may be lost. This is based on the visual judgement and the result is that a sub-model is needed. This is produced by turning the size required for the appropriate sub-model using the master and then re-working it to produce the desired shape.

The copy lathes can also cause some distortion, especially at any sharp edges on the last when other sizes are produced. It is sometimes necessary to produce sub-models at other sizes to enable them to be corrected. This is done by turning the size required for the appropriate sub-model using the master, and then re-working it to sharpen the edges.

Re-working may consist of either removing wood or adding to it. Adding is usually achieved by building it up with a resin filler which can be worked to the new shape.

Any sharp edge on model - such as at the feather - are normally reinforced by inserting flat headed pins which are filed to the shape of the edge.

Having produced a model or a range of models, the production of lasts can be started.

The model is prepared by drilling two holes, which will be used to hold it in the lathe, in the back curve. The line joining the centres of these is generally made perpendicular to the seat of the last. The bottom of the last in this region is normally made flat to help the shoe-making processes but with the periphery of the feather edge lying on a plane. There may, however, be a degree of bottom curvature between the boundary represented by the heel feather. Curvature on lasts from Europe can be quite marked in this region. A single hole is drilled in the bottom of the toe region sufficiently in from the edge to provide strength. This hole is used to hold the toe of the model in the lathe.

Production lasts are turned from a block of plastic, normally a high density grade polyethylene. The block is formed by heating and moulding under low pressure. The main difficulty during moulding is in preventing cavitation. Too rapid cooling of large masses of plastic tends to cause holes to form within the plastic. These are particularly troublesome because they produce cavities on the last surface and weak spots.

After release from the moulds, the blocks are normally cooled rapidly on their surface by placing them in water. They are then stored in an oven which is programmed to gradually cool down.

After cooling, the blocks are trimmed with a saw at both ends to provide two faces to help locate the lathe centres which enable the block to be held and rotated. Any other rough trimming is also done at this stage.

The lathe consists of a pair of rapidly rotating cup cutters attached to a follower mechanism which contacts the model. The model and the block rotate at the same speed. As the model turns, the follower moves according to the model's profile. This motion is relayed to the cutters which cut the block to the shape of the model. The follower is progressed along the model and produces a copy. The block is subjected to a first rough cut. This produces a last shape which is somewhat larger than the desired shape.

The lathes have a facility which enables lasts to be made either larger or smaller than the model for producing a range of sizes, i.e. to grade the lasts. The provision for changing the size from that of the model saves a great deal of time in that new models are not needed for each size and half size. It also helps create greater consistensy between the various sizes. The enlarging facility is useful for making the first rough cut where the last is cut oversize.

After rough cutting, the hinge mechanism is inserted. With, for instance C link hinged lasts, the V notch is cut and the holes are drilled for the spigots which will carry the spring. The holes are used to provide the centre, about which the hinge configuration is cut. The slot in which the spring is housed is also cut and the spring inserted.

After spring insertion, the lasts are fine turned to produce the correct size and shape. The progression of the cutters along the last is slower and the amount of material removed is smaller than for the rough turning operation.

The need to hold the last between the two centres of the lathe results in two extensions: one at the toe and one at the heel. They are referred to as the toe and heel dogs respectively. The toe dog is cut off and the last bottom is this region is planed to shape. The toe end of bottom patterns which have previously been cut to the shape of the model - and enlarged or reuced for the various sizes - are used in this operation to ensure that the toe shape plan is correct.

The heel dog is then removed. The excess material is first cut away and the remaining material is removed in two operations. The first consists of cutting the back curve in one plane using a templet to ensure that the correct line is achieved. The edges produced by the operation are then gently rounded using an abrasive disk to produce the correct heel bowl shape.

In some cases it is necessary to reinforce the bottom of the last by attaching a thin metal sheet. These are cut to shape using the patterns referred to previously. They are cut several at a time and then ground to shape. Holes are punched in them and they are attached with pins. The metal is soft enough to enable it to be hammered to the contours of the last bottom, although a perfect match is sometimes not achieved. Normally the front of the plate is attached and the back portion is cut off at the break line between the back and forepart before being attached separately.

Last bottom reinforcement was a necessary operation in the days when tacks were used to hold the upper to the insole. Its purpose was to turn the tips of the tacks so that they clenched the insole. It is still common to see plated lasts - but for a different reason. Lasts are quite often subjected to much abuse and the plate protects the feather edge from chips and damage.

Some last manufacturers adjust the back height to their lasts to a constant value by machining them. Others allow this parameter to grade. This is some advantage in a constant back height although it is an extra operation and as such has to be paid for. Its advantage is in not having to make adjustments for back moulding and seat lasting.

The final operation is fitting the socket or thimble. During footwear manufacture the last has to be located and held: a hole with a thimble inserted provides the means of doing this. The operation is relatively simple. A hole is drilled and thimble forced into the hole. Some last manufacturers have fairly rigorous standards and grade the position of the thimble, i.e. its position from the back changes between sizes while others set it a constant value.

The accuracy with which it is positioned is not great but it does not need to be. Different sized thimbles are normally used for men's, women's and children's lasts with children's usually having a smaller diameter because of the narrower tops to the last. There is also considerable variation from manufacturer to manufacturer, typically 9-16 mm. The thimble diameter is a compromise between it being small so that it is surrounded by a quantity of plastic to hold it securely in place but not so small that the last jack pins which hold the last are so small in diameter that they break or bend (LASTS, 1990).

Recently new methods of a last production have occured. Current last turning equipment can produce lasts to a high degree of accuracy. Operations such as cutting, hinging and the removal of the toe and heel dogs can reduce the accuracy although it is still possible to work a high degree of precision with the last as well as for positioning any location devices such as gripper plates.

Computerised methods of producing lasts are currently being developed. One involves lathes in which the follower is numerically controlled (NC) rather than by turning from the model. It can produce lasts speedily but a disadvantage is that the toe and heel dogs still have to be removed manually.

The other method is last milling, which is usually done on a 3 axis machine and is slow and not suitable, therefore, for a company needing to produce large numbers of production lasts, but it obviates the need to remove toe and heel dogs.

Undoubtedly in the future, digitised last data will be used to control shoemaking machinery and perhaps for pattern and pre-production operations. Data generated at the model stage could provide the basis for tooling-up and enable it to be carried out even while the lasts are not being made. It is possible to make the graded ranges using the model data with either NC lathes or NC milling equipment.

With accuracy requirements expected to more demanding in the future, NC driven equipment can work to a high degree of accuracy and their use may be justified by this reason alone. It may also be possible to generate and use data during modelling to change the last design. Such techniques could allow changes to be made on screen where they could be judged for style and against dimensional as well as shape guidelines associated with lasts which are known to be satisfactory. Hard copies of models could then be produced for final selection.

2.5 Footwear Manufacture

Footwear is a technical term for shoes, boots, courts, etc. that perform certain primary functions and lesser ones.

The **primary functions** are:

1. To protect the sole of the foot from the heat, cold, dampness, dirt or roughness of the ground. In its simplest form this is achieved in the primitive sandal which is nothing more nor less than a piece of leather, wood or other material, fixed under the foot by a strap or other means;
2. To protect the upper part of the foot and, if required the leg from the cold, rain, thorns and insects or other bites. In its simplest form this is a bag of leather or material wrapped round the foot and is here given the generic name of moccasin.

The **lesser functions** are:

1. To assist the foot to perform some abnormal task in sport, in dancing, in some trades, such as mining, fire-fighting, armed services, etc.;
2. To overcome abnormalities in the foot itself, the surgical boot being an extreme example of this;
3. To complete the costume.

The variety of shoe styles is so bewildering that at first sight it seems impossible to establish the factors which they have in common. Yet these styles are obtained in fact by endless variations on a comparatively few basic themes. It is important to determine which is the theme and which is the variation. In this the acid task is the function that each part fulfills - is it essential to the construction of the shoe and, if so, how and why? Has it a subsidiary function? Or is it merely put there for effect and decoration?

The main footwear types are described below; however, there are a great variety of them.

Shoe is an outer covering for the human foot, especially one, which does not reach above the ankle, usually of leather, and having a hard base, a sole and a support, a heel, under the heel of the foot.

Boot is a covering of leather or rubber for the foot and some part of the leg, usually heavier than a shoe, and with a part of it supporting the ankle.

Wellington boot is a special boot of rubber, which keeps water from the feet, and lower part of the legs.
Sandal is a light shoe made of a flat bottom with bands, especially of leather, to hold it on the foot.

2.5.1 Structure of Shoes

Different types of footwear consist of many various parts and details. These parts are classified as **outside parts, inside parts** and **intermediate parts.** Each of these classes is also subdivided into **upper** and **bottom** parts. The outside upper and bottom parts protect the foot and are responsible for an outer look of footwear. The most responsible outside upper parts of this kind are *vamp, quarter, cap, leg*, etc. The most important inside parts are *insole, lining, facing*, etc. The intermediate parts such as *doubler, stiffener, bottom filler* make footwear stronger and hold it to preserve its form.

UPPERS

A simple upper consists of three basic parts:
The **VAMP** which covers the toes and forepart or front of the shoe.
The **QUARTERS** which enclose the back of the foot.
The top of the shoe which surrounds the opening for the foot is called the **TOPLINE.**
The lower extremity where the upper meets the sole or insole is called the **FEATHER EDGE.**
When the patterns are cut an additional margin is added to the feather edge which allows the upper to be attached to the rest of the shoe. This is called the **LASTING ALLOWANCE** (Fig. 2.12).

The separate functions of vamp and quarters are best seen in an evening shoe with an open middle section or **WAIST** (Fig. 2.13). In normal shoes the vamp is joined to the quarters by a seam. This is often at the waist but the position and method of seaming can vary and this will alter the style of a shoe.

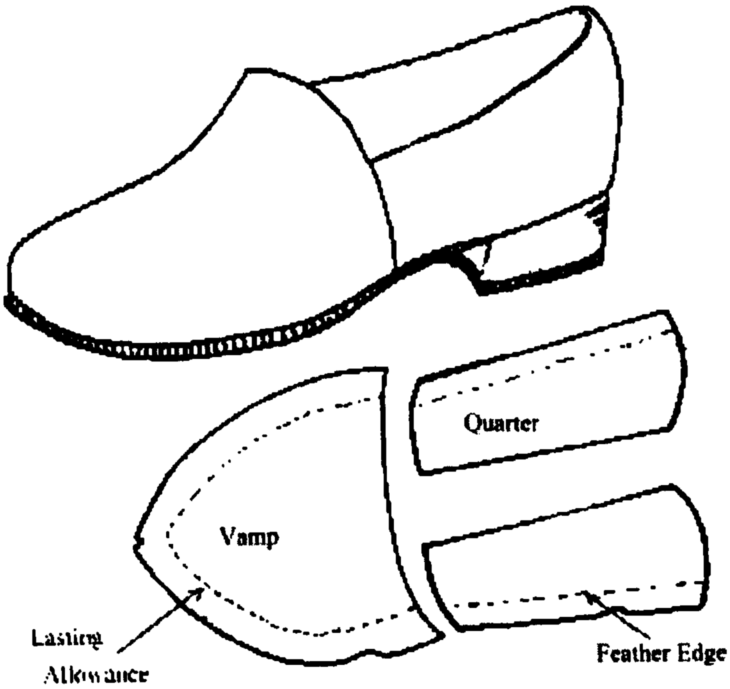


Fig. 2.12 Shoe with simple upper

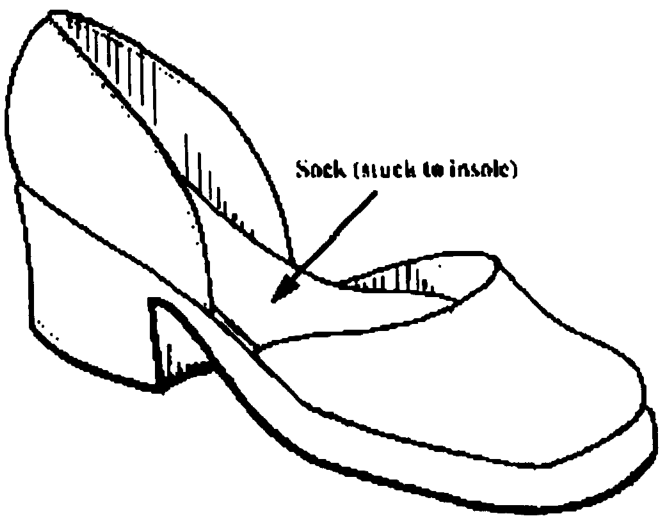


Fig. 2.13 Evening ladies' shoe with waist

The theme outlined for the ladies shoe can be varied further by considering the angle and manner in which the vamp is joined to the quarters. The extent to which the vamp will cause differences in style and fit. For example, men's lace shoes tend to fall into two categories:

OXFORD shoes have the vamp overlapping the quarters with the tongue being separately attached.

DERBY or **GIBSON** shoes have the quarters overlapping the vamp (Fig. 2.14).

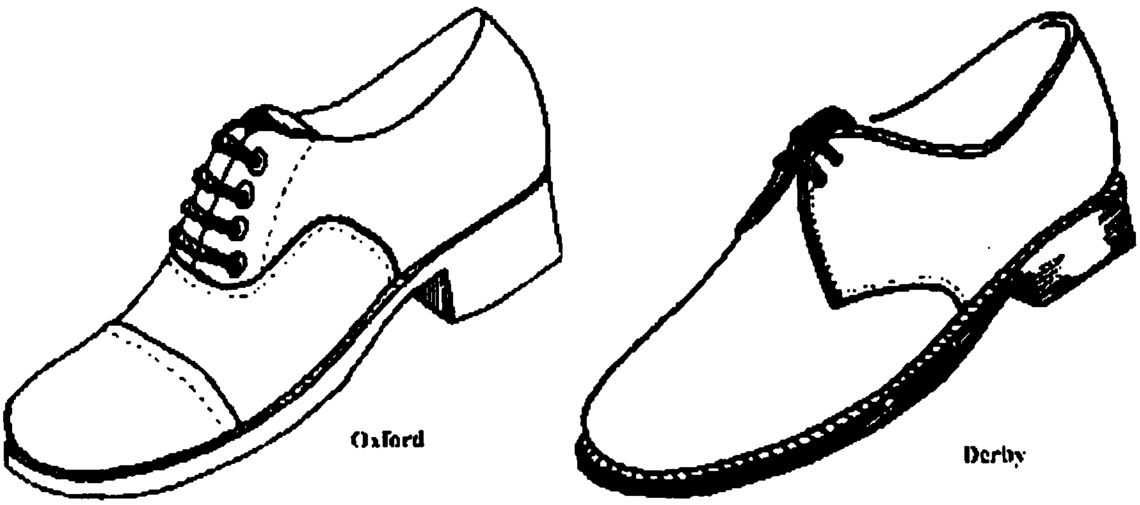


Fig. 2.14 Oxford and Derby shoes

BOTTOMS

This is the term which refers to the whole of the bottom of the shoes as opposed to the upper. It generally includes some of the following, depending on type of construction.

Main stock fitting components are: ***soles, insoles, stiffeners, toe puffs, heels, shanks.***

The **INSOLE** is the inner sole of the shoe which is next to the foot under the shoe sock. Insoles may be made all in one piece or, alternatively, in two pieces. Insole to which the vamp and quarters are lasted and to which the sole attached is also important. A **SOCK** is normally inserted over the insole.

When an insole is made from two pieces it is known as a **BLENDED INSOLE**. The blending insole is made from a flexible forepart and a rigid backing. The rigid insole backing maintains rigidity in the waist. This should not be confused with the term backer which is used to describe material suitable for reinforcing lightweight upper leather or fabrics (Fig. 2.15).

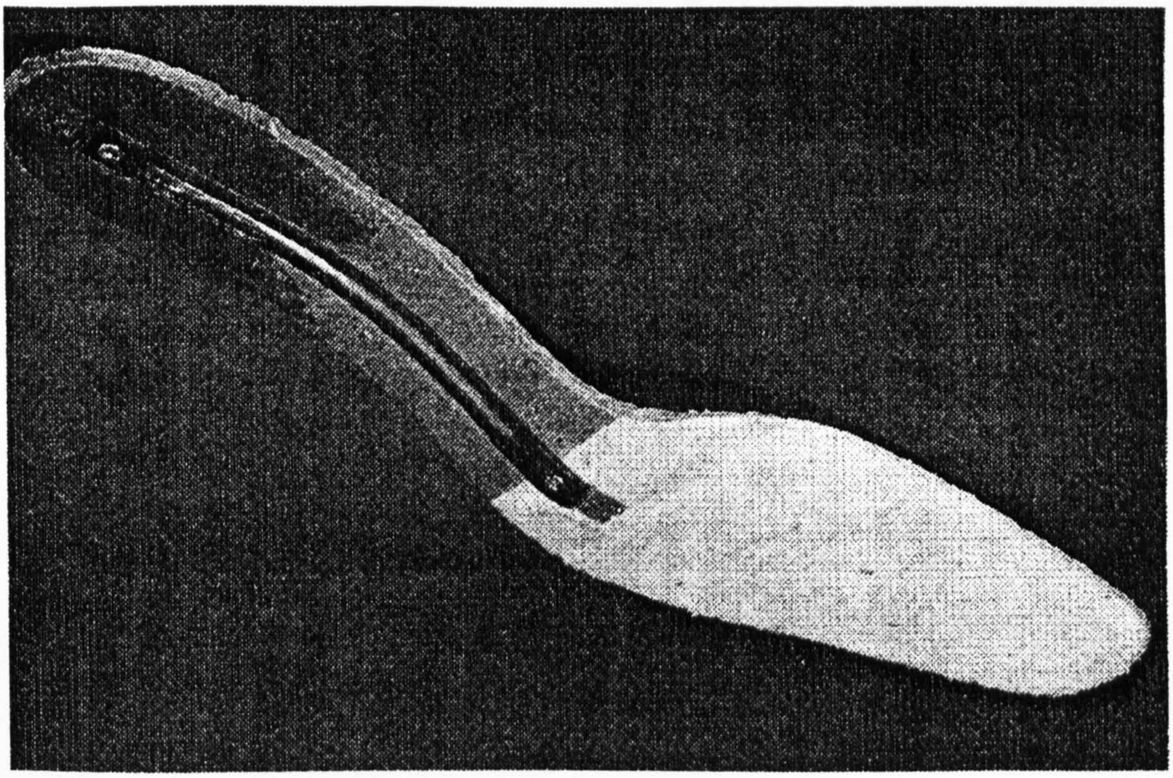


Fig. 2. 15 Blended insole

Insoles prepared for use in **WELTED** construction may have a **FABRIC RIB** attached, to which the welt is stitched (Fig. 2.16).

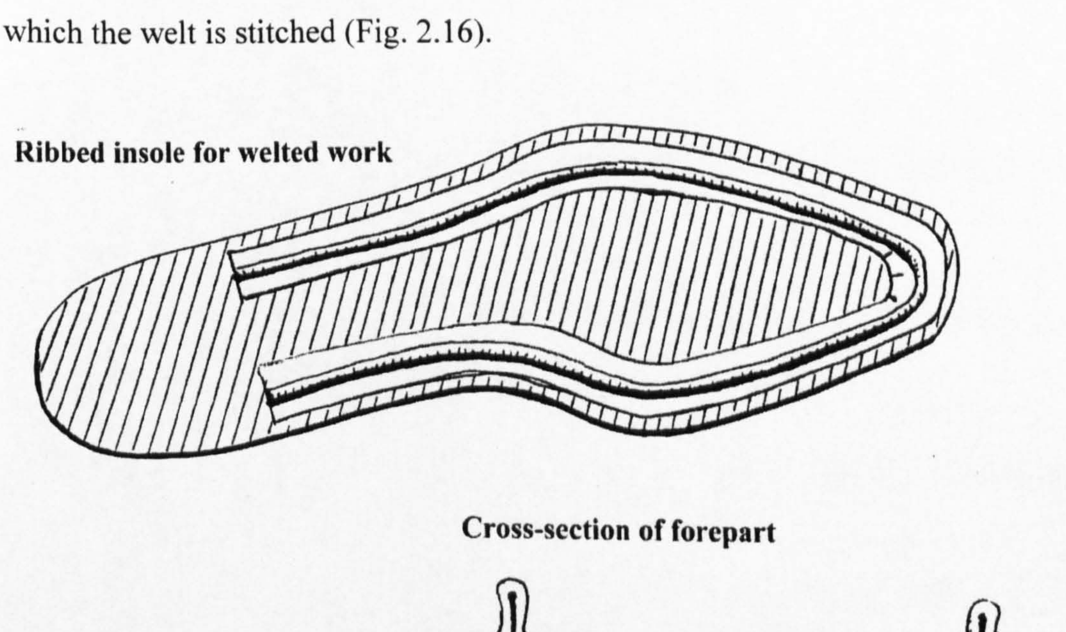


Fig. 2.16 Ribbed insole for welted work

A **SOLE** is the layer of material which covers the bottom of the shoe and is the walking surface of that shoe. Soles are made of a diversity of materials depending on shoe construction to be used. A **HEEL** is the under part of the shoe which supports the heel of the foot, and may be stuck or nailed to the shoe bottom.

A **STIFFENER** is a material shaped to conform to the heel of the last, and inserted between the lining and the upper (Fig. 2.17). A **TOE PUFF** is any suitable material which is placed in toe of the shoe to reproduce the shape of the last and to maintain that shape throughout the active life of the shoe. These parts are intermediate details.

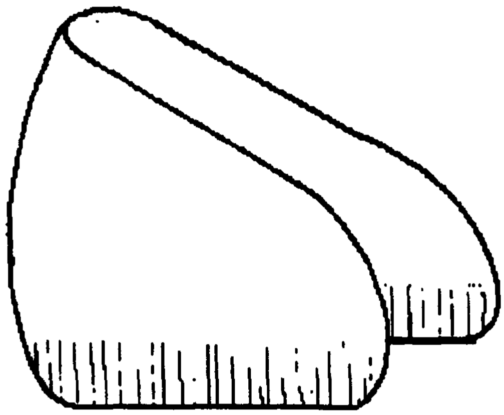


Fig. 2.17 Semi-moulded stiffener

A **SHANK** is a strip of metal or plastic used to reinforce the waist of the shoe. It is placed between insole backer and the sole. Shanks should be pre-moulded to the last bottom curve.

The table below identifies the basic parts which go to make up uppers and bottoms and illustrates these in various styles (Table 2.1).

Types of Footwear	**Parts**	**Outside Parts**	**Inside Parts**	**Intermediate Parts**
1	2	3	4	5
Boots	Upper	Leg, bootfront, vamp, cap, thin counter, outside backstrip, heel draft	Lining, lining backstrip, top band	Doubler, side lining
	Bottom	Sole, half sole, welt, heel, top-piece, heel draft	Insole, loose insole	Platform, middle, bottom filler, stiffener, toe-puff, shoe shank

1	2	3	4	5
Booties, Shoes	Upper	Vamp, quarters, cap, thin counter, tongue, outside backstrip, heel draft	Lining, lining backstrip, facing, top band	Doubler, side lining, interfacing
	Bottom	Sole, half sole, welt, heel, top-piece, heel draft	Insole, loose insole	Platform, middle, bottom filler, stiffener, toe-puff shoe shank
Oxfords	Upper	Vamp, quarters, cap, thin counter, tongue, bead, outside backstrip, heel draft	Lining, facing	Doubler, side lining, interfacing,
	Bottom	Sole, welt, heel, top-piece, heel draft	Insole, loose insole, seat lining	Platform, middle, bottom filler, stiffener, toe-puff shoe shank
Pump-shoes, Sandals	Upper	Vamp, quarters, cap, thin counter, bead, outside backstrip, heel draft	lining	Doubler, side lining
	Bottom	Sole, welt, heel, top-piece, heel draft	Insole, loose insole	Platform, middle, bottom filler, stiffener, toe-puff shoe shank

Table 2.1 Footwear Parts

2.5.2 Common Upper and Bottom Materials

The use of materials of different features for footwear production is conditioned by the demands on the footwear of different assortment and age-gender groups or material structure.

For example, for uppers, lining and insoles of children's shoes it is necessary to use real leather or materials with similar features such as good hygiene and serviceable properties, light weight and flexibility. The bottom material for such shoes should be non-slip, flexible and light. Footwear for youths, men and women should be made of long-wearing materials in order to provide long service.

Another condition to be paid attention to is a season. Special construction of summer shoes allows them not to be made from very hygienic materials. However they should be good painted and be dermatologically tested. Winter footwear are made from materials with low thermal conductivity.

The most common upper materials is real or 'man-made' (synthetic or artificial) leather. Nowdays according to fashion trends and development of high-tech materials more and more footwear uppers are produced from synthetic materials. However, real leather is still the most preferable material for uppers of expensive shoes and one with good hygienic properties.

From time immemorial, leather has been the pre-eminent shoe material due to its unique physical properties. Our predecessors, right down to the recent years, probably never tried to analyze the reasons why leather was so suitable for shoemaking and foot comfort – they knew that it was and took it for granted. Today some of these reasons are becoming more understood. Now we can describe and explain many economic and physical properties, which are obligatory for footwear materials to have. A description of these properties follows.

1. **Elasticity and plasticity** are important not only for shoe upper materials but also for soles and insoles. Even for heels many people prefer an elastic material to soften the blow of putting the foot to the ground in walking on a hard surface.
2. **Strength and Stretch** are very important, though stretch is frequently more important than strength. Stretch is one of the 'hidden' differences that must be closely watched since any error judgement can easily result in an upper that is seriously distorted. Calfskin is an illustration of stretch and lightness. A skin that did not stretch would make movement impossible, and from this necessity of some strength it follows that we would expect to find the greatest amount of stretch where the amount of movement is greatest. This, in the animal, is obviously near the legs, in the belly and across the neck.
3. **Flexibility** is sometimes akin to elasticity and plasticity; it means the ease with which the material may be bent.
4. **Permeability** is the ability of a shoe material to pass air, water and water vapour. It is one of the most important factors contributing to foot comfort.
5. **Thermal conductivity** is the ease with which a shoe material transmits heat, it is yet another important factor in foot comfort.

6. **Abrasion resistance** is the ability of shoe materials to withstand abrasion, that is one of the most desirable properties.
7. **Surface characteristics** include colour, smoothness and pattern.
8. **Chemical constitution and reaction with the foot** is especially important now while specifying new materials, the interaction of which with the foot cannot be ignored and they should certainly be tested for this.
9. **Slippeness** is in other words the coefficient of friction. The importance of non-slip sole is very great.

The virtue of leather is that it possesses so many useful properties compared to material yet discovered; these properties being due to its unique fibrous structure which has not yet been reproduced artificially.

Nowadays in addition to leather other materials such as fabrics and synthetic materials are widely used in footwear production. They are used for upper and bottom parts, for outsides, linings and interlinings. Fabric can be of

1. A vegetable origin, i.e. made of cotton, flax, jute, hemp etc.;
2. An animal origin, i.e. made of silk or wool.

New uses for fabric are continually being introduced into the shoe industry and there seems to be no limit to the variety that is available for different parts of the shoe upper, linings and interlinings.

Canvas is used for sports wear and heavy boots. Poplin produced in a variety of colours is used for lighter weight footwear. Satins, crepes and silk enable selection to be made for evening or dress footwear, while velveteen, rayon or cotton materials are used for high quality dress shoes as well as for every day and sports footwear. Fabrics are intended to reinforce the outsides of leather in footwear and absorb moisture of the foot.

Synthetics have not proved to be very popular for uppers in the shoe industry because of their impermeability to air and water vapour. Earlier used in a shoe upper they comprised 50% or less of the total area. Strips of plastic are used on sandals because of their attractive bright colours. If synthetic materials are to be used in a shoe, then the designer should aim at open-work types of shoes and sandals, or shoes with ventilated uppers, where so much of the foot is exposed to the air that the intimate contact of the upper with the foot in a few places does not seriously affect foot comfort.

There are two main types of synthetic upper materials: the coated fabrics and poromerics. Originally the objective of the development of coated fabrics in footwear was to create a cheaper alternative to leather that at least visually would be as attractive and with adequate durability and some comfort properties, the most important being suppleness and "handle". Coated fabrics tend to be reasonably supple which is very important for ladies shoes. Synthetic upper materials have already established themselves more in women's than in men's footwear. The essential characteristics of upper materials are aesthetics, good processability, durability in wear, adequate comfort and hygiene properties. The relative importance of these characteristics is dependent on the type of footwear. For example, for work shoes, durability, processability and comfort may leave behind aesthetics, whereas in high fashion ladies footwear aesthetics comes first. Impermeability is the main disadvantage of coated materials for uppers.

Another commonly used class of synthetics for upper materials is porous, the essential characteristics of which is high permeability. The main criterion of this material is that it should permit the transport of moisture vapour. The term "poromeric" has been used to describe these materials, the particular structure of which reproduces to some extent the physical properties, but not the actual structure of leather. One can say that poromerics are man-made shoe upper materials which are generally similar in nature and appearance to leather, to build into synthetic materials all the properties of leather is the task of paramount importance of the chemist.

Due to the above, there is nothing so good as leather for upper materials, but it is no longer entirely so - it is quite mistakenly applied to soles. There is no mysterious intrinsic virtue in leather as a sole material - in fact, for most purposes 'man-made' soling is infinitely preferable: it is long-wearing, more weather-proof, more resilient, more flexible and more economical. The old expression: "One can breathe through leather" is almost meaningless so far as soles are concerned, and the widely-held view that 'orthopaedic' alterations and additions cannot be made to rubber-soled shoes is quite erroneous.

There are very few people who cannot comfortably tolerate synthetic sole materials and leather may in some circumstances, as on wet, leafy, shiny pavements, be less prone to slip under people who are already unstable, but otherwise 'rubber' (which includes plastic), wins in every way, although it is wise to take care that the tread is not made with, nor worn down to, a smooth surface which may indeed prove slippery in wet weather. Tender feet may not like thin, hard, plastic soles.

Synthetics are widely used for soles in footwear, urethane being a vivid example. Light weight, flexible, rugged and cheap, urethane is being used for all types of soles – thick and thin rigid and flexible – dress shoes, sporty casuals and joggers, loafers, clogs, wedges, boots, tennis sneakers. Table 2.2 illustrates common footwear materials.

Footwear Materials			
Upper Materials		**Bottom Materials**	
1	2	3	4
1. Leather	**Animal origin:** • Calf-skin • Cowhide • Kid, goat • Pigskin • Horse • Sheep	**1. Leather**	**Animal origin:** • Cattle hide • Horse hide
	Tannage: • Chrome • Semi-chrome • Chrome-vegetable • Mixed • Chamois (oil) (Russian)		**Tannage:** • Mixed oil • Oil
	Surface: • plain • printed (grained) • patent • fleecy (chamois, suede, split, nubuc)	**2. Rubber**	**Shape:** • sheet rubber • moulded rubber • all-rubber soles
2. Artificial and Synthetic Leather	• **Coated fabrics** • **Porous**		**Structure:** • Crepe • Sponge • Microporous • Non-porous • Transparent

1	2	3	4
3. Textile Fabrics	a) **Animal:** wool, silk b) **Artificial:** rayon, acetate c) **Synthetic:** nylon, capron, lavsan		**Method of construction:** • Adhesive • Hot cure
4. Combination Upper		**3. Plastics**	**Chemical structure:** • Polypropylene • Polyethylene • Polyamide • Polyvinyl chloride • Polyurethane
			Method of construction: • Adhesive • Moulding
		4. Wood and Metal	

Table 2.2 Footwear Materials

2.5.3 Footwear Manufacturing Process

The old craft trades, of which boot and shoe manufacture is one, are, to a large extent, being revolutionarized by the application of better machines and a more scientific and mechanical approach to all problems. Footwear manufacture has become one of the most developed and mechanised branches of light industry. It is no longer one craftsman's work; it is a complex process involving a lot of people and machines. It embraces many processes indeed, the main of which being the following.

Traditionally, shoe manufacturing begins with the design and manufacture of the prototype last which is a highly skilled and time consuming operation, and is hence expensive, as it is still a totally manual operation, relying heavily on the skill of the last technician.

When a design of shoes has been agreed to be passed to the production line, last grading related to the master last must be done.

Last grading is a duplicate process from the model last to several other different sizes to confirm with the needs of customers. Grading can be arithmetic (constant increment) or geometric (percentage increment) or to user-specified rules.

Once the desired last has been obtained, the designing process begins. First of all, stylists who prefer to handle a 3D object design directly onto a last surface. Once accepted, the 3D style can be flattened to produce the 2D patterns. Flattening is a flat representation of the top surface area of the last. Manual flattening is a skilled task requiring many subjective decisions. The flattening of a design is a crucial part of the operation. It is impossible, due to the shape of a last, to flatten its surface without creating distortions. The critical element is to introduce these necessary distortions where the upper materials and the lasting process will be able to cope with them.

An alternative 2D method of designing is obtaining a forme. The forme is a type of a flat representation of one side of the upper surface of the last as a basis for shoe upper pattern. On the forme the stylist makes a standard which is represented as a plan of the upper viewed from one side. When necessary a whole-cut standard can be produced.

Now the design of the shoe can be established on the forme by the stylist. Then sectional patterns are made fòr every part of the upper from the standard patterns. All of the allowances for such items as folded edges and seams must be added during cutting the sectional patterns and stitch marks should be included.

After finishing the design process in either 2D or 3D in order to produce different range of sizes the grading of the shoe pattern should be proposed from the original model. The process is to increase or to decrease each part of the original pattern to a proportional size.

The next step is pattern cutting - the foundation of all subsequent shoemaking operations. It is essential, therefore, that all patterns should be 100% accurate. The action of cutting the component can be either by hand or machine.

Basic modern methods of cutting available to the industry are continuous cutting using water jet, laser or reciprocating knife as the cutting medium or die cutting. In the case of leather, defects and the geometry of the hide must be taken into account. Man-made materials, because of their uniformity, can be cut multi-thick and need much less skill in cutting than leather. Recently, automatic lay planning techniques have become available what enables to save time and materials in comparison with traditional cutting techniques.

Concerning bottoming components - they are bought ready or prepared in a stock fitting department of a factory. Again, when designing the components, tooling-up and for working parts of machines this is the model last that serves as the main information base.

To achieve the end of the shoe manufacturing it is necessary then to assemble and mould the upper and to attach the prepared bottoming components. A method of shoe construction is chosen according to the purpose, material and modern fashion and is the subject for special attention.

Different methods for shoe construction are based on different ways of attachment of sole and upper. There are many methods, which are described here.

Welted. Features: the upper and insole are sewn to the welt, which is stitched to the sole. No seam visible inside, a flexible method for men's and women's shoes (Fig. 2.19).

1 - insole;

2 – chain stitch seam uniting insole, upper and welt;

3 – welt;

4 – lock-stitch seam securing sole to welt;

5 – bottom filling;

6 – sole.

Silhouwelt. Features: similar to welted but the outsole is stuck on to the welt, which is narrower and lighter. A flexible method for women's shoes (Fig. 2.20).

1 – insole;

2 – chain stitch seam uniting insole, upper and welt;

3 – welt;

4 – bottom filling;

5 – sole, attached by adhesive only.

Lock stitch through sewn welt. Features: the welt and upper are joined to the insole by a vertical seam passing right through it. Sole stitched to welt as in welted method. Simpler and cheaper than the orthodox welted method but not so flexible and seam shows inside (Fig. 2.21).

1 – insole;

2 – littleway staples securing upper to sole;

3 – lock stitch seam uniting insole, upper and welt;

4 – lock-stitch seam securing sole to welt;

5 – welt;

6 – bottom filling;

7 – sole.

Fairstitched. The insole, upper and middlesole are sewn together. The sole is then stitched to the projecting edge of the middlesole (fairstitching) (Fig. 2.22).

Moccasin. Features: the upper passes right under the foot. A middlesole is stitched on to the upper and the sole stitched on to the middlesole edge. A very flexible and waterproof construction for sports and casual shoes. A variation of the method is used for slippers (Fig. 2.23).

1 – "butt" seam joining upper and "apron";

2 – upper extending completely under the foot;

3 – lock stitch seam uniting upper and middlesole ;

4 – middlesole;

5 – lock-stitch seam securing sole to middlesole;

6 – sole.

Machine-sewn (Blake or Mckay). Features: sole, upper and insole are united by a single chain-stitch seam. Used for medium-grade women's shoes. Variations of the method include the use of 'Littleway' lasting staples (which do not show on the insole) and a lock stitch in place of the chain stitch, giving added flexibility (Fig. 2.24).

1 – insole;

2 – lasting tacks securing upper to sole;

3 – chain stitch seam uniting sole, upper and insole ;

4 – bottom filling;

5 – sole.

Cemented. Features: the upper secured to the insole by 'Littleway' staples and then a cellulose or similar cement attaches the sole. A large proposition of women's, children's shoes and sometimes men's lightweight shoes are made cemented. The method can be made to look heavier by extending the sole and stitching a 'rand' or false welt around the edge (Fig. 2.25).

1 – insole;

2 – 'Littleway' tacks securing side of upper to sole;

3 – bottom filling;

4 – sole attached by adhesive.

Riveted. Features: the sole is riveted through the upper to the insole. Used for football boots and cheap boy's boots and shoes being a rigid method of construction (Fig. 2.26).

1 – insole;

2 – lasting tacks securing upper to sole;

Riveted, screwed and stitched. Features: uses three methods of attachment: (1) middlesole is riveted through the upper to the insole as in the previous method, (2) the sole is stitched to the projecting edge of the middlesole, (3) the sole, middlesole, upper and insole are united by screwing. Omitting one of the attachments can vary the method. Widely used for army and other heavy-duty boots (Fig. 2.27).

1 – insole;

2 – lasting tacks securing upper to sole;

3 – rivets uniting middlesole, upper and insole;

4 – middlesole;

5 – lock-stitch seam securing sole to middlesole;

6 – hobnails;

7 – standard screws uniting sole, middlesole and insole;

8 – sole.

Turnshoe. Features: a single-sole of exceptional flexibility and with only a very light sole edge showing. The upper and sole are sewn together and the shoe then 'turned'. Used for high-grade women's shoes and slippers (Fig. 2.28).

1 – sole;

2 – chain-stitch seam uniting upper to sole; the stitching is done while the shoe is inside out, before turning;

3 – upper;

4 – lining;

5 – note absence of insole and light edge compared with full substance of sole.

Veldtshoen. Features: the upper is turned outwards and stitched to the sole (as at 'A'). A variation is to stitch a crepe rubber middle (or a crepe faced leather middle) on to the flange, and then to stick a crepe sole on to this (as at 'B') (Fig. 2.29).

A) – single row of stitching;

2 – rand;

3 – outflanged upper;

4 – leather sole;

B) – double row of stitching;

2 – outflanged upper;

3 – crepe-faced leather runner;

4 – crepe sole attached by adhesive.

Slip-lasted (California). Features: the upper is stitched on to a sock lining and a platform cover. A last is forced into the upper to give it its shape, the platform (and wedge heel) are stuck in position and their edges covered. Finally, the sole is stuck on.

A cheap method of construction for women's sandals, light fashion shoes and slippers (Fig. 2.30).

1 – sock lining;

2 – seam uniting sock lining and upper;

3 – seam uniting sock lining, upper and platform cover;

4 – platform cover, cemented to bottom of platform;

5 – platform;

6 – sole attached by adhesive.

Direct Moulded Construction. A) with imitation welt, b) with 'curtain' edge. Features: the upper is lasted to an insole and the bottom roughed and coated with an adhesive as for a normal cemented shoe. The rubber sole and heel unit is then actually moulded and vulcanised under the lasted upper and pressure bonded to it.

During closing various types of machines are used and in this connection NC-means are of great interest. A good example of this is use of computers in automatic cutting, stitching and lasting. Automatic roughing and cementing machines are also available.

When producing footwear manually all pre-production, production and finishing operations are made by high-skilled shoemaker and therefore are to be of high quality and very expensive.

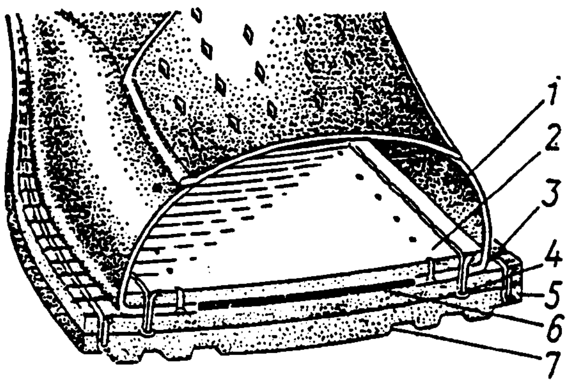


Fig. 2.22 Fairstitched shoe construction method

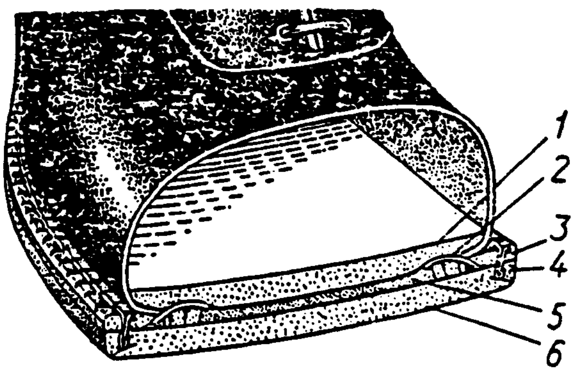


Fig. 2.19 Welted shoe construction method

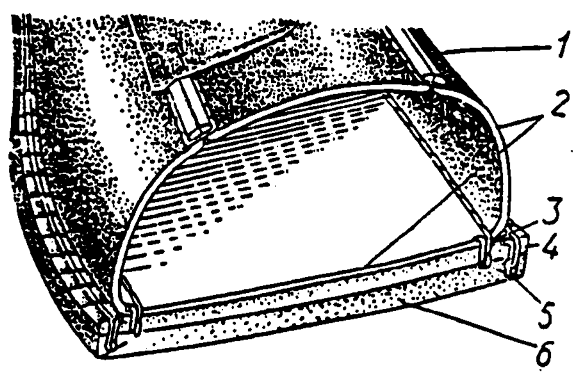


Fig. 2.23 Mocassin shoe construction method

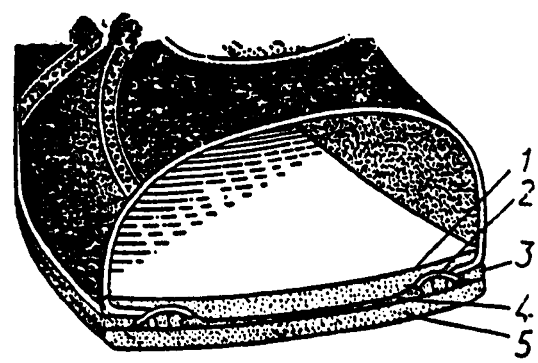


Fig. 2.20 Silhouwelt shoe construction method

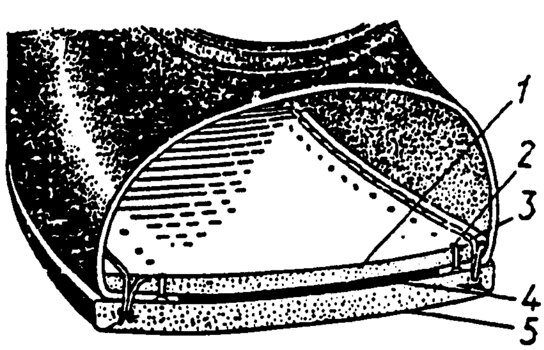


Fig. 2.24 Machine-sewn (Blake or Mckay) shoe construction method

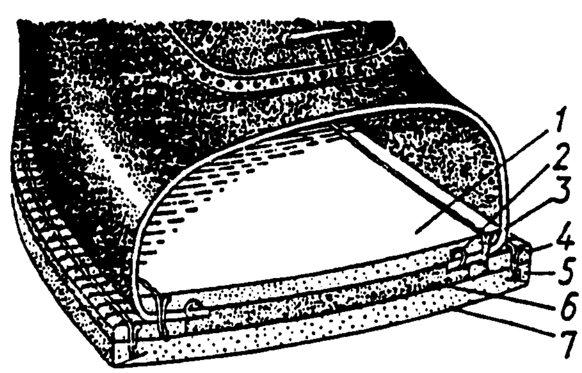


Fig. 2.21 Lock-stitch through-sewn welt shoe construction method

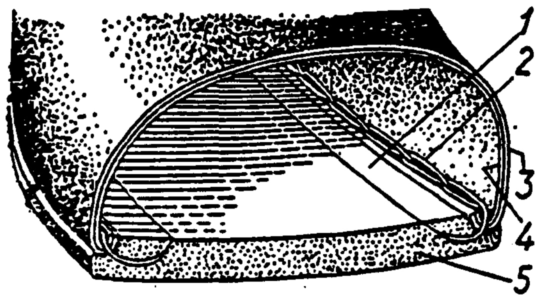


Fig. 2.28 Turnshoe shoe construction method

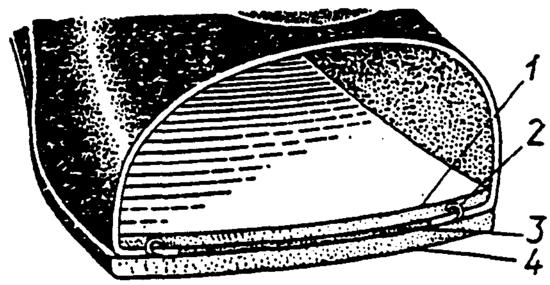


Fig. 2.25 Cemented shoe construction method

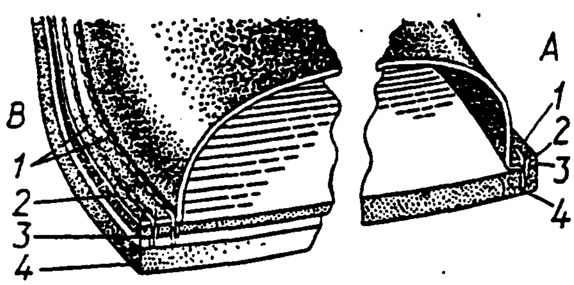


Fig. 2.29 Veldtshoen shoe construction method

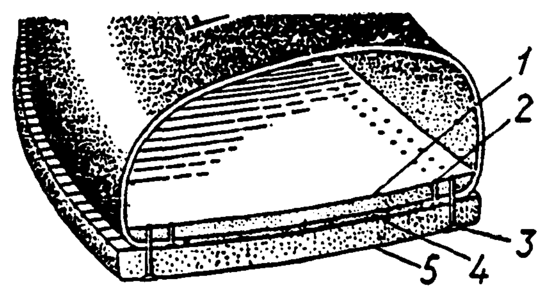


Fig. 2.26 Riveted shoe construction method

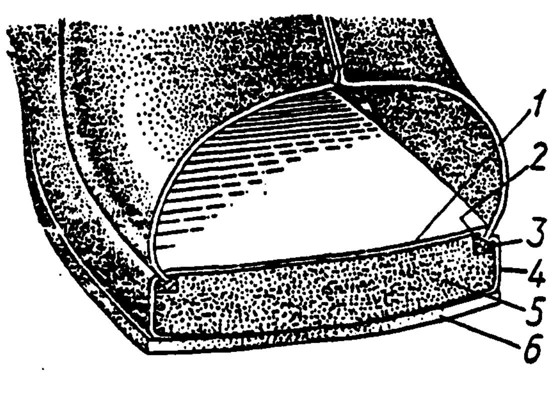


Fig. 2.30 Slip-lasted (California)

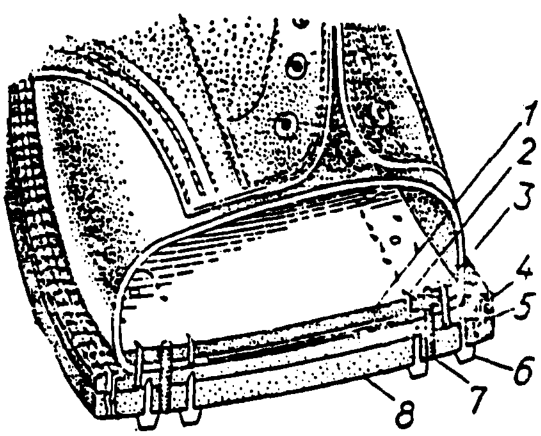


Fig. 2.27 Riveted, screwed and stitched shoe construction method

Chapter 3. Measurement Systems

Introduction

The demand for footwear, which fits as perfectly as possible, has led to many efforts to arrive at a satisfactory standard of foot measurement. Perfect fitting footwear implies the best shapes for given materials and methods of construction, in accordance with the purposes for which the boot or shoe was designed. Thus we are confronted with a number of factors from which arise varied and peculiar problems, of which the chief can be stated as follows:

- how to measure and specify the characteristics of a foot, or a group of feet;
- what shall be the shape of a last for the purpose required;
- what are the best shapes to ensure good fitting properties when footwear is made in bulk production.

3.1 Foot Measurement Systems

3.1.1 Methods and Technology

The feature of anthropometric measurement of a foot is necessity to measure each foot with the aim to define individual parameters. Depending on the goal of the investigation the measuring program will include 40 or more different parameters - linear and girths.

The particular program depends on the tasks to be investigated and could include the following set of parameters:

Linear:

- length of the foot;
- width of the foot in the ball joint (internal and external) and in the middle of the seat;

These parameters are defined from the impression that formed by the most projected surface parts;

Girths: perimeters of cross-sections in:

- ball joint;
- waist;
- instep;
- short heel.

When designing bespoke shoes and lasts the impression and plantogram are used and perimeters and the shape of the cross-sections are also taken into account. The horizontal sections and their height are measured as well.

The **methods of foot sizing** available are different and listed below:

1) X-ray method

The X-ray method reveals peculiarities of a structure of the foot bones arrangement and the foot as a whole. Results of this research are very valuable for the diagnostics of the foot condition. However, the X-ray method is mainly used in stationary conditions and is harmful to health if often used. With the help of X-ray beams the images of the bodies are taken when standing as well as while moving.

By analysing X-ray images and plantograms appropriate to them it is possible not only to characterise the foot morphology, but also to reveal development of abnormalities.

2) Method of Taking Plantogram

The plantogram is the image of a plantar surface of the foot, preserving enough information for the last designing. Comparison research shows, that the plantogram characterises the majority of the peculiarities of the foot structure and reflects exactly morphological infringements. Therefore, the plantogram can provide the foot attributes describing its morphological condition without complicated X-ray researches of the foot on mass measurement.

3) Method of Plaster Cast

Plaster cast method supplies the last-maker with the most complete data for transition from the foot dimensions and form to those of the last. However, production of the cast is a rather labour intensive and complex process, the basic operations of which are as follows:

- preparation of the foot and plaster mass for manufacturing a matrix (negative);
- preparation of the matrix and plaster mass to produce the positive;
- Obtaining the foot positive.

4) Biomechanic, Physiological and other methods cover special foot-sizing devices. A significant amount of construction of foot-sizing devices exist that differ in purpose, degree of complexity and principles of measurement.

On purpose, foot-sizing devices could be subdivided by the order of increasing complexity into:

- Devices for footwear fitting (length, foot width and more seldom - ball joint girth are measured);
- Devices for measuring the foot (length, width measurements, the impression, girths: ball joint, waist joint, short heel, ankle, calf (ZIBIN, KLUCHNIKOVA, KOCHETKOVA and FUKIN, 1982);
- Devices for anthropometric researches (the number of parameters measured can be estimated in tens).

On **degree of complexity** devices are subdivided into:

- Means to measure the foot manually;
- Seem-automatic means;
- Automatic devices.

By principles of operation devices can be subdivided into contact and non-contact, and by methods of measurement into plantographs, linear sizes, and 3D form and perimeters.

The devices for anthropometric research provide exact measurements for a large number of parameters; thus not only separate sizes and girths are taken but also the shape of cross-sections or the foot as a whole. Two groups of devices for this purpose are available - these are plantographs and devices for measuring contours of sections (more often cross-sections) of the lateral surface of the foot. The devices getting foot images from different points by photographing make the separate group.

However, the plantogram does not allow defining volumetric parameters of the foot and the shank. For such measurements a large group of contact devices (METHOD AND DEVICE FOR MEASURING CHILD'S FOOT, 1991; METHOD AND INSTRUMENT FOR MEASURING FOOT PRINT, 1991; DEVICE FOR MEASURING SHAPE AND PARAMETERS OF A FOOT, 1983) have been developed that have frameworks or sets of test probes for measuring sections in a plane of a framework. (MEDZERYAN, FARNIEVA and PAVLIN, 1974; MEDZERYAN, AVERINA and PAVLIN, 1986; BOLEYEV and FUKIN, 1982). For simultaneous measurements of length, several width and girth parameters there are other foot-measuring devices (KOCHETKOVA and KLUCHNIKOVA, 1991; BENNO, BROWNE, 1994).

The disadvantage of such contact methods is that it causes discomfort for the customer because of the large number of probes placing pressure on the foot. The form of representing the results does not meet requirements accepted by the measurement program, that needs the additional analysis of data (ABOLINA, 1988). Low reliability of such devices because of obvious complexity and demand to each probe to guarantee given accuracy of measurement are additional disadvantages of the devices.

In general low productivity and complexity of service is a feature of contact devices and their application is limited only to laboratory researches. Speed of measurement with the help of the devices is not faster and frequently even slower than hand-operated measuring. Attempts to automate the process of contact measurement resulted in complicated designs and great restriction of parameters measured because of the necessity to position in each local zone of measurement.

Such integrated and high-speed methods as photographic ones preserve a lot of information but allow only projection images and do not readily allow measurements of volumetric parameters and forms of the foot sections (KARAGEZYAN, KOMISSAROV, BISTROVA, NAZAROV and TARVERDUAN, 1989).

Moreover, the processes of photo processing are time consuming and labour intensive, the image analysis is made manually, the accuracy of measurements is low. Usually the images of several foot projections on a background of co-ordinate grid are taken with the help of system of mirrors. The advantage is that immediate fixing of the foot situation allows investigating a dynamics of walking and comforting for the client is provided (ILCHENKO, FARNIEVA, BABAEV and NOVACK, 1987).

The exception is photographic techniques, using methods of light section (FUKIN, 1986), of moiré effect (MOLYAVCKO, MUTALLINOV and BELOUS, 1977) and stereo-photogrammetry (PASHAEV and FAMINCIN, 1978; RODE, FUKIN and KISELEV, 1991). These methods create 3D parameters of the foot surface but require special conditions of processing and are considerably more difficult than normal photo processing. They have common faults of the photographic methods of the foot measurement: lots of steps, analogue preservation a lot of the results, complexity of data processing and impossibility of automation. It complicates practical application of the specified methods.

The most perfect is the series of the devices which use video-cameras in the system with a microcomputer, developed in the last few years in USA (GARDNER and others, 1985). In these devices the foot is located on a transparent support, and an image of the foot contour is produced by the digital video-camera. On co-ordinates of a contour the processor reads the foot parameters and even the parameters of the footwear parts. Thus, use of television has produced greater information, which allows the device to be used for measurement in CAD. The devices in recent years which use laser illumination are also known (PETER and RICHARD, 1987).

To study the process of walking and the foot work in dynamics they use films (ILCHENKO et al, 1987) and recently video recording (KOMISSAROV and ALECKSEYEV, 1992), that allows to get operative result at the expense of photo processing.

Problem of automation the process of the footwear designing on the basis of anthropometric data or for individual foot is recently faced to (FUKIN, KOSTILEVA, and LIBA, 1987; KARAGEZYAN, KOMISSAROV, ALECKSEYEV and GOZMAN, 1992). The similar works are known world-wide, and on a basis of non-contact automatic device for measuring the foot in system with the computer and processing the lasts by NC-means (PETER and RICHARD, 1988).

According to recent publications it could be concluded that works are urgent in Russia and abroad in a direction of creation automatic foot-sizing devices working in the system with the computer (KARAGEZYAN, KOMISSAROV and ARISLANOVA, 1991). Thus it is supposed continuous measurement of the foot surface with the subsequent analysis of the form by software, that permits to solve a problem of high-grade measurement by the automatic device (KOMISSAROV and others, 1991).

For example, the work of automatic device (WAY AND ELECTRONIC DEVICE FOR MEASURING A FOOT, 1986) is based on application of tele-camera with photo-receiver integrated with the computer, a high speed of measurement being provided. Besides the device does not contain movable parts. Integrated system of measuring the foot and manufacturing individual last and footwear (INTEGRATED SYSTEM FOR MEASURING A FOOT, MANUFACTURING LASTS AND FOOTWEAR, 1991), based on use of a scanner for reception of a plantar foot surface image is also interesting. For processing the image a special technique (SYSTEM OF VISUALIZING, CATALOGING AND ATTACHING FOOT AND FOOTWEAR, 1991) of transferring to individual last by a way of selection the most suitable last from the library (METHOD OF MEASURING A FOOT FOR LASTS MANUFACTURING, 1991) is developed.

A device (PETER et al, 1988), intended for non-contact measurement of the foot surface by a laser in a system with a computer for designing individual footwear offers large opportunities. The main disadvantage of the device is its use of expensive mechanical scanners.

A development by the firm CAMP Limited is in this connection interesting. This is the system called "FootScan" (Fig. 4.2b). Instead of tape measurements, the patients sits on a 'scanner chair' whilst a total of four laser and eight cameras take 400 000 points of reference of each foot which immediately present a series of 3D images on the computer screen. Though there is the capability then to select a last design from the library and mill it by NC-means, to get the finished pair of shoes with exceptionally high degree of accuracy, to assess faster and more accurate, resulting in a better fitting shoes, the disadvantages of the system are high cost, complexity and surplus information.

Another interesting system announced by Computerised Footwear Systems is Digitoe that could be considered to be one of the latest development in the area. It utilises the latest computer technology to scan the individual foot and create a pair of custom designed "shoe lasts" to match the individual feet (DEVELOPMENTS IN COMPUTER-AIDED DESIGN FOR FOOTWEAR, 1996). However, the technique again means selecting the most appropriate last from the library to match the foot.

The latest development in this area is a foot-sizing device SC-100 of American company CMI that is combined with CAD/CAM system "Shoemaster" of English company Clarks (NEW PRODUCTS, 1996). The advantage of the device is high speed, and the possibility to scan the whole foot and shank surface with presenting the output information as cross-sections with increments of 5 mm. Besides it is of great importance and interest, that afterwards the data are translated into the above mentioned system "Compu-Last" for manufacturing the last. However, the model last is still chosen from the library pursuant to individual data.

Analysing the above-stated methods and means of anthropometric measurements, one can allocate the following requirements to the devices in a system of computer last designing:

- Automatic non-contact measurement of high speed;
- Opportunity to define the character of the foot surface similarly to a plaster cast;
- High-speed measurement of all necessary parameters of the foot with an error 1-2 mm (ZIBIN et al, 1982) in 1-2 minute;
- Comfort provided to a customer, minimum time and simplicity of preparation for measurements, complete automation of measurement process;
- Opportunity to change the program of measurement, to record and document the results;

- Low cost enough for short-running enterprises of manufacturing individual footwear.

The above requirements are satisfied by an automatic non-contact foot measuring device invented in the Leningrad State Institute of Textile and Light Industries named after S.M. Kirov in 1987. It preserves all the advantages of the above automatic non-contact devices and provides complete three-co-ordinate sizing of the foot surface (KARAGEZYAN, KOMISSAROV, GOZMAN and ORSHANSKIY, 1990; KOMISSAROV, 1987) with the use of video-cameras. It does not contain any movable mechanical elements, is low cost and all parts are widely available. Besides by the means of the device it is possible to get foot data with the back part raised to the necessary heel height. All this recommends the given device for use in systems of last designing based on individual data.

The creation and introduction of non-contact high-speed automatic devices permits to increase speed and reliability of data preparation for footwear CAD/CAM systems, that is a condition of an increase of their efficiency, and provides an opportunity of designing in interactive mode. Modern CAD/CAM systems are described in the following chapter.

3.1.2 Common Measuring Systems

To the problem of establishing more accurate and systematic methods of measuring the feet much inventive skill has been applied in recent years.

The basis for the Russian method of measuring the foot was the principle of defining all external anatomical foot points in a co-ordinate system used while designing a last. The foot is measured in the same points and cross-sections as the last relative to the following:

- The foot should be oriented to the chosen axis;
- The location of each key point is measured on three axes - length, width, and height. The ordinate axis is tangent to the inner contour of the foot in the most projected points of metatarsus-phalangeal joint and the heel, the abscissa axis runs perpendicular to the latter and is tangent to the most projected point of the back part;

- All length parameters are defined by *Y* co-ordinates; width parameters - by *X*-co-ordinates; height parameters - by *Z* co-ordinates from the ground plane (Fig. 3.1).

The Russian system of foot measurement has some differences from that of the UK but they are basically similar. The main difference is that in Russia the foot measuring is perpendicular to the co-ordinate planes, while English method uses slope measurements.

This is because the majority of English measurements are not taken directly from foot measurement but from a library of existing lasts in order to control the last shape. The Russian method takes into account transmission from foot data to last data in accordance with traditions of last designing.

In order to design the particular last according to common Russian rules and constraints of last designing the perpendicular system will be used further.

3.1.3 Measurements Required for Last Modelling

Numerous methods of measuring a foot are practised; some simple and others complicated. A competent bespoke shoemaker, who selects the last and measures the foot, needs few measurements because he can visualise the general shape and characteristics. If measurements are to be sent to another maker, then fuller particulars and more details are necessary, especially when the feet are abnormal.

So, there are different interpretation of foot measurements for the last manufacturer, shoe manufacturer and retailer.

Complete and accurate foot measurements are needed for the last manufacturer so that a better-fitted last can be produced. For this when measuring manually we need the following procedures to be made according to the UK method (Fig. 3.2):

<u>DRAFT OF THE FOOT</u>

Place the foot with weight on in the space provided on the appropriate piece of paper and draw a line round with pencil held perfectly up right. A sketch should be taken of both feet. (For bespoke work any corns, a cross on the sketch, starting if on top, side or under the foot should indicate tender places or abnormalities).

The location of the measurements should be marked upon the side of the draft, when an outline of the foot with weight-on has been undertaken.

IMPRESSION OF THE FOOT

An impression is of great value. To make it means a reproduction of the bearing surface of the foot produced by standing upon a kind of transparent paper. It can show the distribution of weight, also indicate the toe shape and the tread line, and the area around the tread line which is bearing most of the weight. The first essential towards a good fit is to ensure that the last be of correct bottom in shape and surface.

The **length of the foot** requires to be taken when the foot is bearing weight, because it will give an accurate length when the foot is fully extended (The following girth measurement should be taken in the same condition). Then one projects the rearmost point of the back of the heel to the ground and measures the distance between this point and the rearmost one of the first or second toe. This measurement is the most important as it serves as the starting point for last designing.

At the same time, the **heel-to-ball** measurement can be taken with the length of the foot measurement. The length is from heel to the metatarsus-phalangeal joint of the big toe.

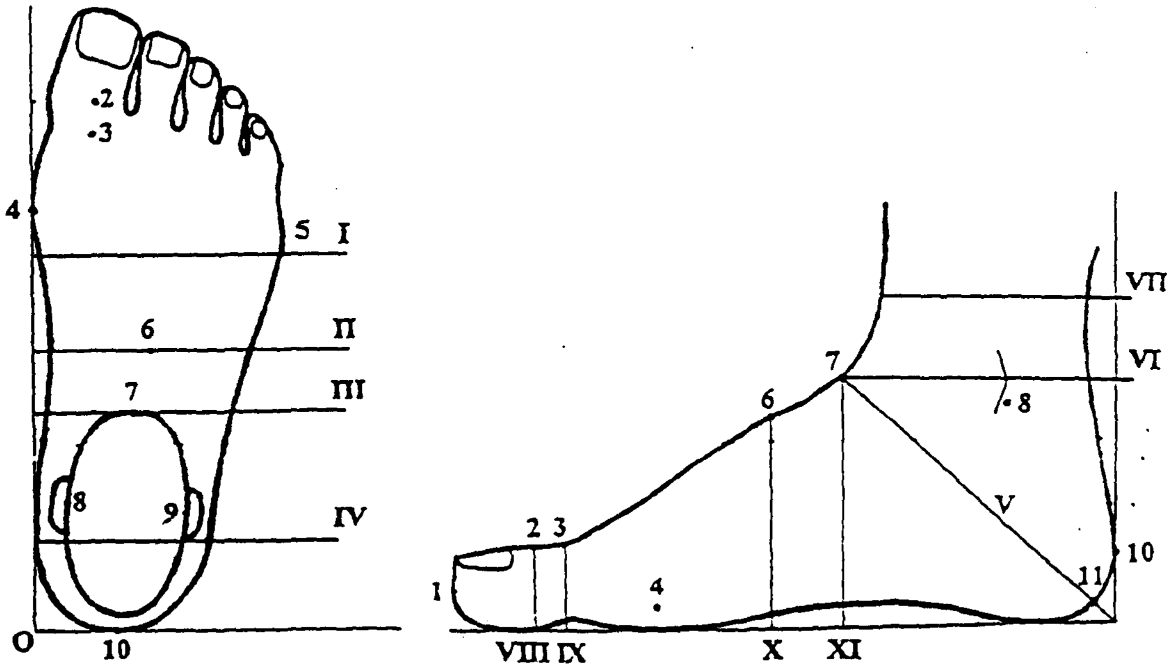


Fig. 3.1 Foot measurements according to Russian method

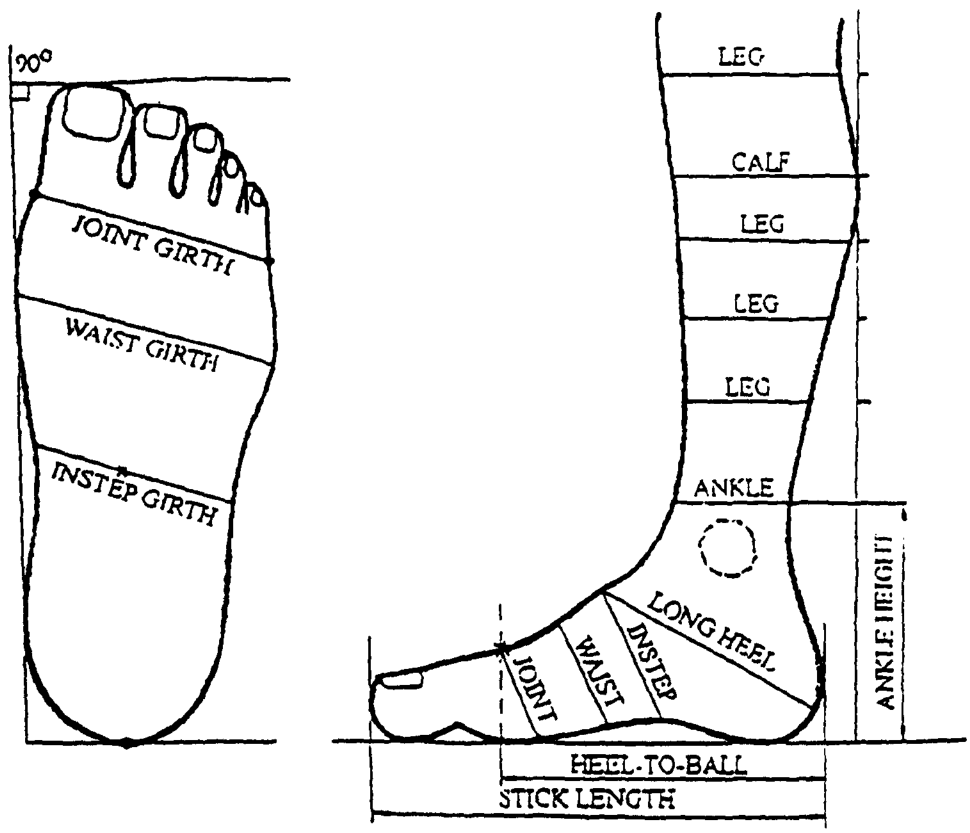


Fig. 3.2 Foot measurements according to the UK method

Since the back part of the last has been standardised, the heel-to-ball measurement has become one of the important pieces of information for last bulk production.

The **ball joint girth** should be taken at the metatarsus-phalangeal joint around the big toe and small toe of the foot. The tape measure is commonly used for taking the girth measurement. The joint measurement then is converted into a width fitting of the last.

The **waist girth** is the smallest girth behind the joint. Sometimes, several attempts are required in order to find the smallest girth.

The **instep** measurement is taken by passing the tape over the prominent bone of the foot, which is in the middle cuneiform.

The **seat** is taken under the bottom of the heel (making use of plantogram). The greatest width is required. This is of particular importance as used for adequate last back part designing.

The **short heel** measurement is taken from the seat to the top part of the instep and round the ball of the heel.

The **ankle** measurement is taken by dropping one end of the location tape down to the inner side of the heel. This will indicate the distance, which is from the anklebone to the seat. The **ankle girth** measurement is taken around the leg passing the ankle.

The difference for the Russian method of last designing is that it is necessary, instead of heel-to-ball or instep, to take the following measurements as illustrated in Fig. 3.1:

- Foot width (distance on line of I cross-section);
- The deepest point for the 1st and 2nd toe (point 2) to the base surface on line VIII;
- The height of the big toe (point 3) to the base surface on line IX;
- The height of instep point (point 6, line X);
- The height of foot flexes point (point 7, line XI).

The location of the key foot points is expressed as a percentage of the length of the foot.

As the two methods are very similar we could define the *essential data to measure for last designing:*

- Plantogram of the foot;
- Length of the foot;
- Profile of the foot;
- Key cross-sections in the characteristic areas of the foot:
- Waist cross-section;
- Ball joint cross-section;
- Toe cross-section;
- Back part width;
- Particular additional data for the individual foot, if it is necessary for bespoke shoes.

The amount of foot measurements for the shoe manufacturers tends to be more important for the bulk shoe manufacturer to build up a statistical model of the average foot for different sizes and fittings, better sizing and fitting footwear can then be provided. Again, it is based on taking detailed measurements of the foot.

The other factors, which affect a satisfactory fitting, should be considered, e.g. the styles or materials of shoes. For instance, lady's court shoes have less fitting tolerance than other styles. Because this type of shoe has covered only 1/3 of the front of the foot, therefore they need to fit feet perfectly. Synthetic material provides less ability to achieve a satisfactory fit for varied foot lengths and widths due to its inferior elastisity. Ideally, adequate foot measurements that would be helpful to the shoe manufacturer to produce better shoes are those measurements, which would then fit the largest population in a specific market.

The purpose of foot measurement for the shoe retailers is to offer a pair of suitable shoes for a customer to try on. There are a number of measuring devices mentioned above which is available today. However only two measurements (length and width) are usually taken and it is not sufficient to define a foot accurately. It can only provide a suggested size and fitting of shoes for the customer to try on.

3.2 Last Measurement

Usually lasts are measured in order to control their forms, to copy the model lasts for production purposes or to digitise the last surface into a CAD system for further pattern styling.

To control the shape of the last manually either a set of flat samples designed by the stylist (bottom pattern, heel curve, toe profile, slides in toes (*0.9L*), ball joint (*0.68L*), heel (*0.07L, 0.18L*)), or several standard measurements are commonly used.

Russian State Standard for lasts (FOOTWEAR LASTS. RUSSIAN STATE STANDARD N3927-88, 1990) rations the following main measurements:

- Back part width and girth;
- Ball joint width and girth;
- Short heel girth;
- Width of the outer part of the insole shank;
- Toe extension;
- Toe spring;
- Toe profile height within the interval *0,9L - 1,0L*;
- Back cone height;
- Width of the cone top plane in section *0.07 L* and *0.18 L*;

and few others.

When producing lasts in bulk, model last data is required. Prototypes are usually measured by the same non-contact devices as for feet or by specific ones for lasts (KARAGEZYAN et al, 1991; KOMISSAROV, 1987). There is also specially designed manufacturing equipment that produces the production lasts in lefts and rights by simultaneous copying of the prototype.

The input of the last surfaces into the CAD system is made by means of 3D digitizers. The most common types, because they are relatively cheap, are manual digitizers, but, of course, they are the most labour-intensive. The technique is to take approximately 300 co-ordinates from a pre-marked last surface in a known order using a hand held pointing device. These co-ordinates are taken to produce either a patchwork or a series of vertical and horizontal stripes.

Automatic tactile digitizers are also available but are rarely used at present in footwear CAD. They use a pressure-sensitive probe to determine the last surface co-ordinates. Around 30,000 are taken and processed down to approximately 300.

Laser digitizers emit a low-powered beam of parallel coherent light, the surface reflection of which is sensed by video cameras. The last, coated white is fixed in a rig so that it can rotate. The received data is processed by CAD system down to approximately 300 surface points to define the last surface. Style lines can be captured only if they are drawn on the last in a highly contrasting colour (usually black). The latest developments in the area are non-contact electronic scanner advocated by USM (DEVELOPMENTS IN COMPUTER-AIDED DESIGN FOR FOOTWEAR, 1996).

3.3 Sizing Systems

In general, sizes and fittings are exactly the same between shoe and last. There are different sizing systems for different countries, with scales being the main key for the sizing system for each country.

3.3.1 Sizing and Fitting Classifications

In bulk production, the last manufacturers use general classifications of last terms of sets including sizes and fittings. Size is defined as length of last, fitting is the girth measurement in the ball joint. There are several sets of lasts such as for infants, children, boys, girls, maids, youths, ladies and men.

There are still a number of different sizing systems for lasts and shoes used world-wide making it difficult to fit shoes in a store. The most common sizing systems are English, Paris Point and Metric ones.

Continental Sizing and Fitting (PARIS POINT)

The continental sizing system uses a metric scale, which starts from size 1. The interval for the length is 2/3 cm (6.67 mm) and 5 mm for width. For the men's size range, it starts from 40 to 46 and for ladies - from 35 to 40. The standard size for men's is 41 and 42 and for women it is 36 or 37.

English Sizing System

The English sizing system implemented a numbering system from size 0 to size 13 for children, and from size 1 to 13 for the next group such as women, men etc.

There is 1/3 inch interval between the sizes and 1/6 inch between half sizes and size 0 commences at 4 inches. It depends on manufacturers to indicate the width fitting either using a letter or a number. For men, usually they use either a letter or a number. A letter is commonly used for children and ladies. For men middle fitting usually size 4 or D and size 1 is the smallest. For ladies, AA, AAA are narrower than A. For the wider sizes, EE, EEE are wider than E etc. Normally, D is indicated for middle size. There is a standard measurement of ¼ inch (6.5 mm) for the various men's and lady's girth measurements while for children it is 3/16 (5 mm) up to size 10.

American Sizing

There is a similarity between English and American sizing. American sizing is divided into three different size types such as Standard, Custom and Boston. The interval is 1/3 inch for the length and one quarter of an inch is the width increment. Starting from size 1 to 13 for adult and from 0 to 13 for children's. Ladies' standard sizes are size 6 and B fitting, men's is 8 and D fitting.

The Boston sizing system is usually for making men's footwear. Each Boston size is equivalent to English sizes plus 1/12 of an inch.

The Standard size system is usually used for lady's closed shoes. Size 0 is 3½ inch and for American Standard size 1 ½ is equivalent to the English size 0.

The Custom Size is a specific system for marking sandals. Starting from 3 1/6 inch which is 1/3 inch smaller than the Standard' sizes, the main reason for using this system is to recognise and distinguish between closed shoes and sandals. This is because sandals do not need as much toe allowance as closed shoes do.

The complete range of American fittings is from AAAA for the narrowest width fitting and then AAA, AA, A, B, C, D, E, EE, EEE, and EEEE as the widest width fitting. The eleven fittings are divided into three groups: AAAA, AAA and AA are catalogued into the slim fitting group as A, B and C is medium group, and the remaining user is in the wide group.

Centimetre Sizing and Fitting

This centimetre sizing starts from 1 cm which is size 1 and the length interval is 1 cm and the width-fitting interval is 7.5 mm. These increments are bigger than English increments and there are half sizes within the Centimetre system, which are mainly used in Eastern Europe countries.

Mondopoint

Mondopoint is the international sizing system for footwear based on the millimetre. The size marked on the shoe will consist of two numbers (e.g. 260/95). The first number is the size and corresponds to the length of the foot in millimetres. The second number is the width and corresponds to the joint width of the foot. A shoe marked 260/95 is expected to fit a foot whose length is 260 mm (weight-on measurement).

As Paris Point, as well as English sizing system of last and shoes numeration do not meet modern international metrological demands and are essentially conditional because all last parameters except the bottom length are measured in cm. The foot is measured in the same terms.

The advantage of the inch system over the Paris Point is less value of the interval in length of the shoe between sizes (4,23 mm instead of 6,67 mm). But inch system is much more complicated than the Paris Point.

The advantage of the inch system over the Paris Point is less value of the interval in length of the shoe between sizes (4,23 mm instead of 6,67 mm). But inch system is much more complicated than the Paris Point.

Metric numeration of lasts is now used in Russia; the numbers depend on the foot length in mm. The interval between sizes is 5.0 mm and the interval between fittings is 8.0 mm for casual footwear and 6.0 mm for high-heeled shoes and for children.

The advantage of the metric numeration of lasts is that it facilitates last and shoes designing as with the basis of their constructing the human foot measurements. Moreover, the metric numeration is unified for all types of shoes, socks and stockings.

The metric system of last numeration is going to replace the others in most countries. However the definition of the number of the shoe or insole according to the foot length is not made in the same way in different countries, and as far as the same intervals in length and width in different systems are different it is very difficult to transfer the last size between the systems. Fig. 3.3 illustrates the scheme of such transferring.

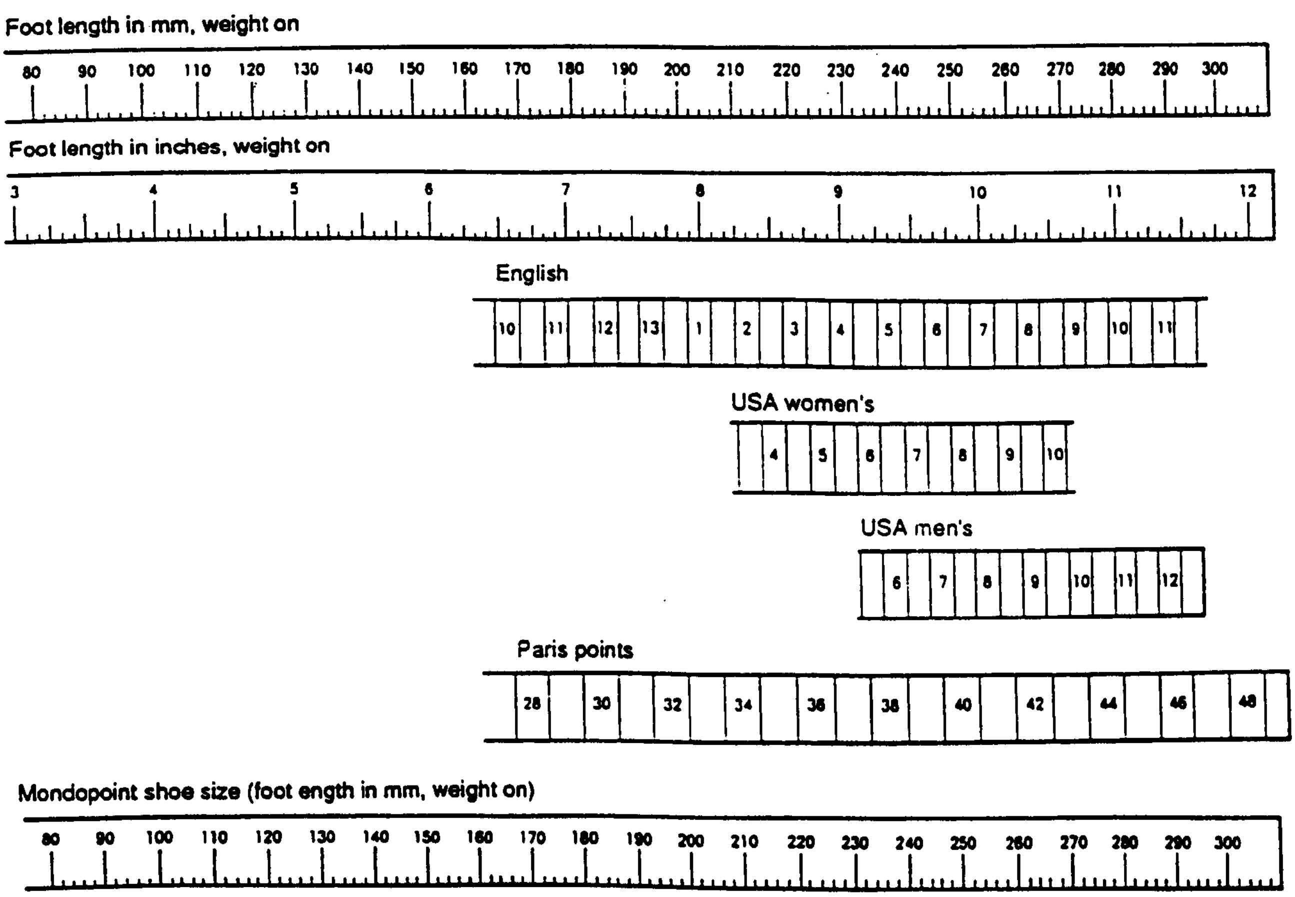


Fig. 3.3 Scheme of transferring the last size between different sizing systems

3.3.2 Grading

When a design of shoes has been agreed to be passed to the production line, the process to make a last is also needed for that particular design. Also, when the last is about to go to the production line, last grading related to the master last must be done.

So, last grading is a duplicate process from the model last to several other different sizes to conform to the needs of customers.

New footwear designs are initially made on sample size lasts, but when the style is accepted for bulk production a complete size-range of patterns has to be produced. To do this the sample patterns must be graded and this is done on a grading machine or by CAD system, although in the past all pattern grading was manual. The process is to increase or decrease each part of the original pattern to a proportional size.

Lasts and patterns are graded separately in 2D according to various rules of grading. Although, some modern CAD/CAM systems allow the facility to grade the lasts in 3D, it is efficient only if the last should be produced by NC-means.

The complexity consists in discrepancy of axes of the last and its patterns, the last and footwear parts, the footwear parts between themselves.

There are different grading systems used in the world and the British and Russian approaches are now examined.

ENGLISH SYSTEM

LAST GRADING METHODS

The last model size for women is 4 or 5; children's is 12; and men's is 8. These size models will determine the production of lasts for the whole range.

There are two grading systems that are frequently used: straight grading and co-ordinate grading.

- *Straight Grading*

From the one model, a whole size range of straight grades is produced. The whole lasts are graded with the same proportion and the same shape as the model last. Therefore, lasts have an identical shape throughout the size range, making the assembly of components in tooling-up a more straightforward operation. Distortion at the seat and waist region is avoided because each last has the same bottom contour.

The only changes are toe spring and heel pitch, which are according to the distortion of the last shape and all sizes of shoe can be produced with the same lines and proportions and style as the sample shoes.

The straight graded process of last production results in heel heights, which grade with size (Fig. 3.4). Lasts and therefore, shoes have heel heights in proportion to their length over the size range. One argument put forward against straight grading is that the higher heels on larger sizes will not be acceptable to taller women who will, in general, purchase the larger sizes, because the higher heels will make them look even taller. The opposite argument is applied to smaller women who will appear smaller but want to wear shoes on higher heels.

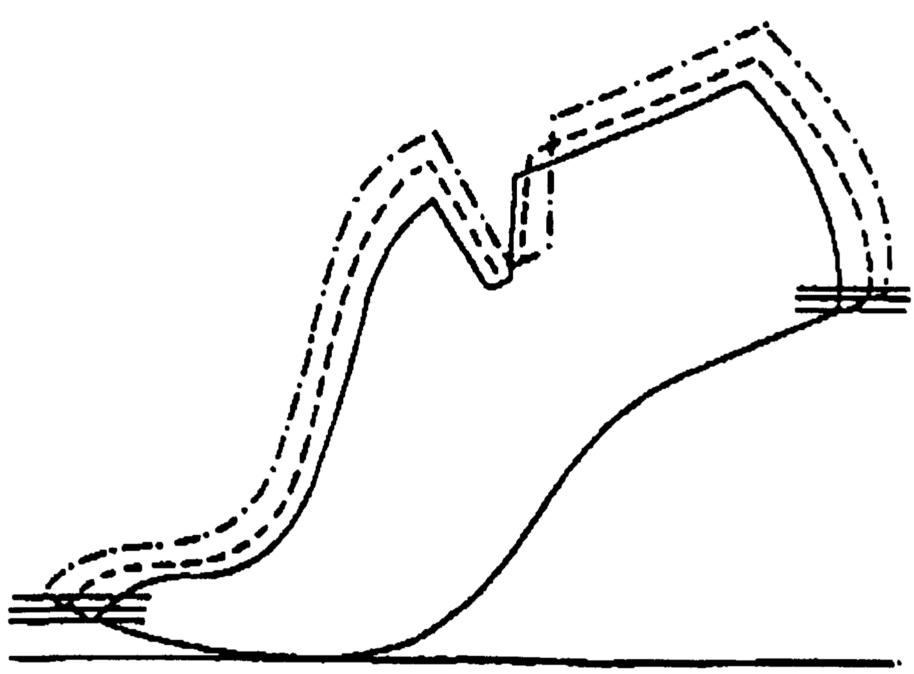


Fig. 3.4 Scheme of transferring the last size between different sizing systems

- ***Co-ordinate Grading***

Co-ordination originated in the USA in the mid 1930s, probably as a means of reducing the number of heels needed for the extensive ranges of fitting then manufactured. Today, in the absence of multi-fitting ranges the main objective of co-ordination is to achieve the same heel height for all sizes.

Sub-models are produced from a basic model and these are then cut and wedged and remained at the same heel height as the master model's. Every size could be adjusted in this manner but to save time and efforts, various sizes are selected as sub-models and after modification the other sizes are turned from them. This results in a small amount of variation in heel height (within a few millimetres) between the models and the sizes, which are turned from them.

There are two methods of co-ordination: full co-ordination and semi co-ordination (Fig. 3.5-3.8). Both have a dramatic effect on the shape of the last, especially in the heel waist region.

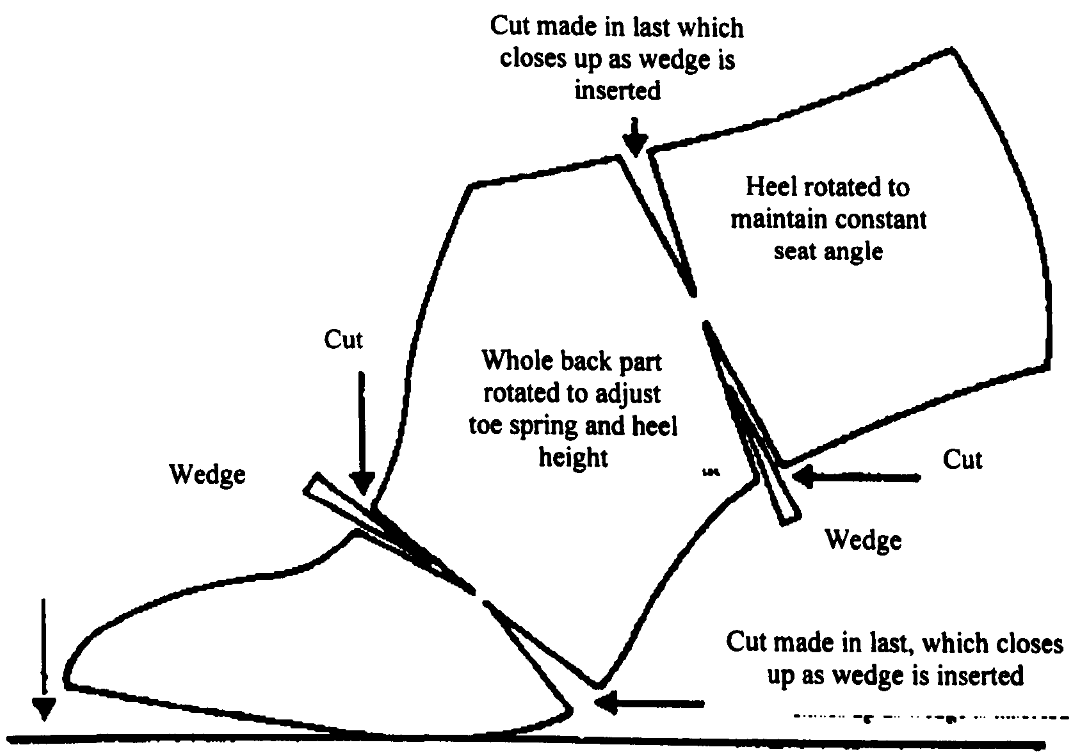


Fig. 3.5 Fully co-ordinated last, showing cutting and wedging

Full co-ordination, with restrictions to give the same heel height, seats angle and toe spring, causes distortion on the upper pattern grade and shank curves. This makes insole moulding a problem. Larger size heels are lower in height at the breast while smaller heels are higher due to the change in seat length. But in the case only one heel group is required.

Semi co-ordination, with restrictions to give the same heel height and toe spring, causes distortion to the upper pattern grade and changes the heel seat angles. The shank curve remains the same.

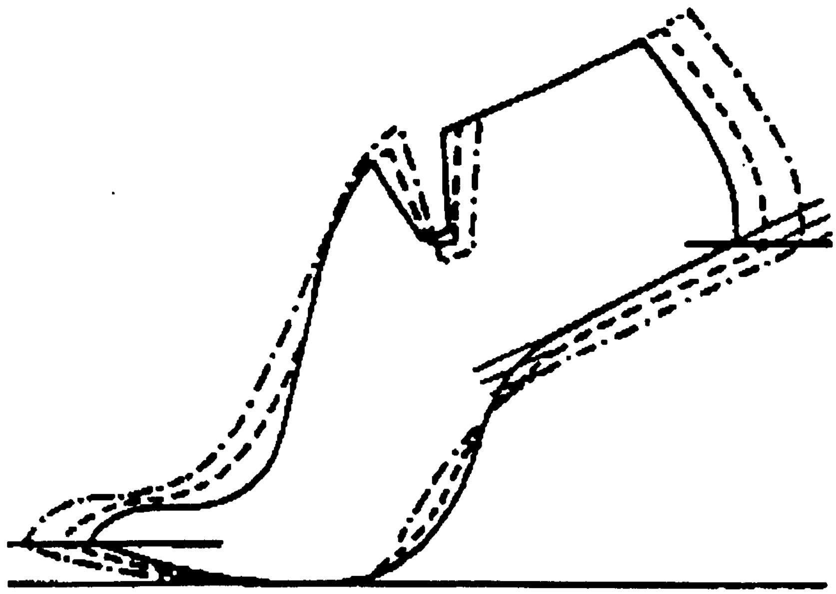


Fig. 3.6 Full co-ordination with restrictions

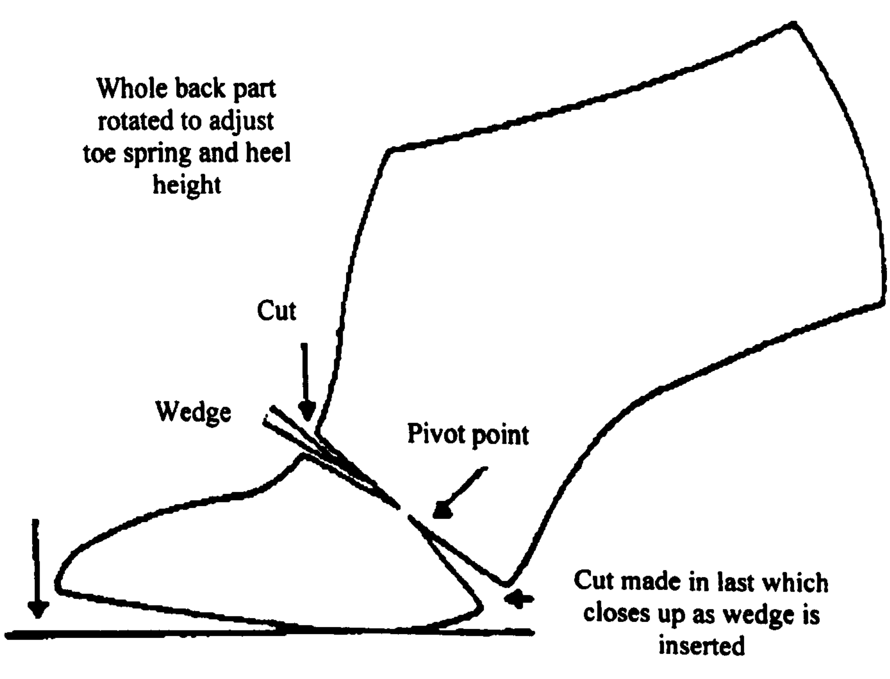


Fig. 3.7 Semi-co-ordinated last, showing cutting and wedging

Although co-ordination achieves a constant heel height there cannot be any aesthetic argument for doing this. A designer's main aim should be to create ranges in which each size looks as much the same as possible. Co-ordination does not achieve this: it distorts the bottom shape and the proportions of heel height to shoe length.

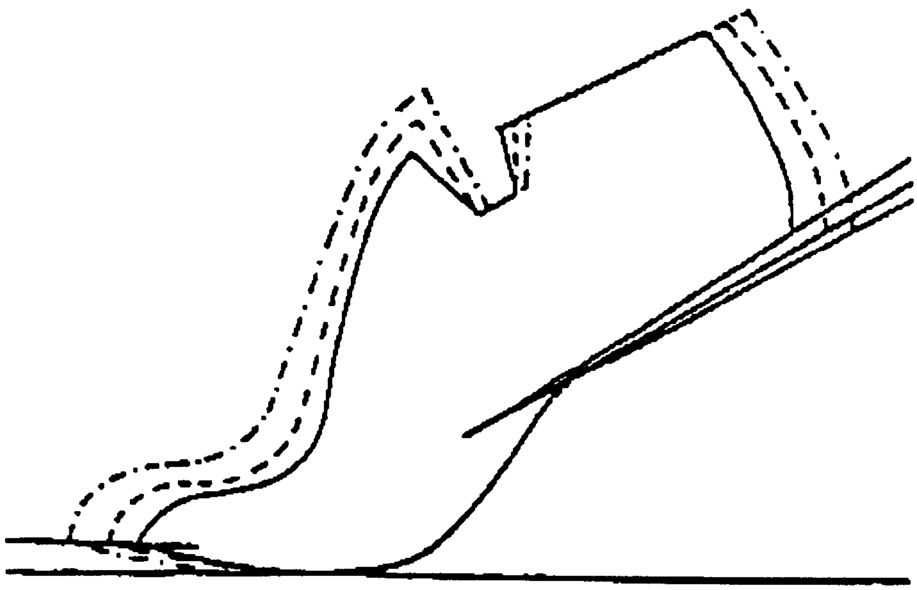


Fig. 3.8 Semi-co-ordination with restrictions

- *Comparison of straight and co-ordinated lasts.*

Perhaps the most misunderstood aspect of co-ordinated ranges is their apparent link with heel grouping. The grouping of heels to minimise the number of moulds needed as an important feature of modern shoe manufacture because it reduces costs and tooling-up time.

With co-ordinated ranges, a separate heel is used for each of the sub-groups and some slight mismatch between last and heel in terms of height is inevitable within the groups. Also within the groups, slight adjustments are needed to the periphery of the seat region of each last so that the same heel fits all lasts within the group.

With straight grading, the heel height grade between sizes is exactly the same as that between sizes within any sub-model group in the co-ordinated ranges. It is impossible to use the same number of heels for a size range as are used with co-ordinated grading, with no greater degree of mismatch provided that the lasts are grouped as for co-ordinated ranges and the seats within the groups are adjusted to fit the same heel.

Not all ranges involve three heels: some manufacturers want to use more and some less. However, no matter how many are used, the use of straight graded lasts will result in no greater degree of mismatch than with co-ordinated lasts.

Another popular misconception about straight graded lasts is that toe spring is adversely affected – changing throughout the range by an unacceptable amount. In fact, the changes are very small: the difference between the toe spring of the model and the extreme sizes being about 1 mm for high heels, less for lower heels.

Both full and semi-co-ordination change the basic shape of the last and there is a need to take this into account when grading upper patterns. Quite often this is not done: it leads to an upper which does not fit the last properly.

With the larger sizes this change in last shape results in patterns with too much spring in the quarters; and with the smaller sizes it results in too little spring. This leads to excess material at either the bottom or the top of the quarters, depending upon the size, which can result in excessive strains at lasting. Straight graded lasts would avoid this situation and lead to better shoemaking.

Adjustments in the draft line may also be needed at lasting to allow for changes between sizes on co-ordinated ranges. No such adjustment is needed on straight graded lasts.

Co-ordination also affects the relationship between insole length and stick length. When the sub-models are cut and wedged, those larger than the basic model become slightly longer, while those smaller than the model reduce slightly in length. The insole lengths, however, do not change by the same amount. This effect and the subsequent adjustments of the stick length to provide the correct stick length grade between the sizes, result in an incorrect grade on the insoles. It also leads to a difference in upper pattern requirements between sizes, which is often not taken into account. Straight graded ranges avoid this difficulty and provide a better match of upper to last.

Normally three insole moulds would be needed to adequately cover a fully co-ordinated range of lasts. Fewer would be needed with semi-co-ordinated ranges where the differences in waist shape are not as marked. However, if straight graded lasts are used, only one mould is needed because the bottom profiles are the same throughout the range. This is again seen as a positive advantage: response time will be improved and the possibility of a mismatch on some sizes – where moulds do not exist – is avoided.

As with insoles, three or more shank shapes may be needed for fully co-ordinated ranges but only one if lasts are straight graded. Different lengths are needed to avoid premature breakdown in the heel region of the shoe, however, and if fluted shanks are to be used there is little chance of reducing the number of formers needed for straight graded ranges.

However, the constant shape of the waist and seat region associated with straight grading is thought to be a positive help in obtaining a better fit with less chance of having to 'make do' with poorly fitting shanks for some sizes in an attempt to save the cost of extra tools, as can happen now with co-ordinated ranges.

LAST GRADING SYSTEMS

The term *grading system* combines two features: one is the *method* by which the lasts grow and the other is the *amount*. In general, different sizes are produced using a system called Arithmetic grading. Another system, Geometric grading is little used today.

- ***Arithmetic Grading***

Here the intervals between sizes are constant. The amount by which the girth or width grows is, however, different, from the length interval although it is constant between sizes. The length grows by 1/3 inch, the joint girth by ¼ inch and the width by 1/12 inch. This means that the method by which the last grows is not proportional because the width or growth grows at a different rate from the length. In effect, the last tends to grow at a smaller rate in terms of girth or width than it does in length so that lasts that are longer than the model tend to get slimmer than to their length. Lasts that are smaller than the model tend to get fatter.

- ***Geometric Grading***

With this system the interval is based on a percentage growth (3% between sizes) so that the size of the interval between sizes changes. Larger lasts have longer intervals between them and smaller lasts, smaller intervals. The width and girth also change at the same percentage rate, which ensures that the last retains its proportions.

In reality, however, there is little difference between lasts graded by either method. The true origin of the arithmetic grade is not known but it has become established practice. Geometric grading was the result of a quest for a system, which would be suited to the introduction of automation, is clearly linked with it. The method fell into disuse but it is not known why. Discussions with various footwear manufacturers suggest that its demise resulted from a lack of progress in automated and automatic equipment, which was the main reason for its introduction.

There has been a renewed interest in automation and it may be worth reconsidering what the geometric grade has to offer in terms of positional information and if this could help the movement to automation. The UMSCo feels the following are its main advantages (LASTS, 1990):

- The style does not change throughout the size range.
- Upper patterns can be graded to fit all sizes from one model.

The method of grading the backparts reduces the number of counters or heels needed if multiple ranges are being produced. This would be of considerable interest where extensive ranges are produced.

The system proposes a system whereby the foreparts and backparts of lasts can be interchanged. This will lead to reduced costs as only foreparts need be changed when fashion dictates new lasts. This is not unique to geometric grading.

PATTERN GRADING

Pattern grading is based on the geometric principle of "similar triangles" which proves that triangles with corresponding angles equal are said to be similar - that is although they may differ in size they are the same proportions and shape. The important point with regard to pattern grading is that their corresponding sides are proportional.

The properties of similar triangles make possible the proportional enlargement of any shape or figure by means of "radial projection". This means that from a radial point either inside or outside the figure, radial lines are drawn through the outline of the figure and the required increase or decrease in size is marked on the radial lines. The proportional dividers or a radial tools used are also a series of triangles.

When patterns are graded by machine, pantographs are used to put the principle into effect. The pantograph - which is in effect a flexible rectangle with extended arms - is also designed and built on the geometric principle of similar triangles.

When grading patterns, the angles between the lines, which form the pattern will stay the same on all sizes and all lines, will increase in proportion to each other. So if the toe cap of a particular style was half the overall length of the vamp on the model (sample) size, it will still remain half the length after grading has taken place, regardless of which size is examined.

Before grading any particular set of patterns, note must always be taken of the grade increments of the lasts on which the uppers are to be made. As said above, most lasts do not grade in the same proportions for both length and width. English lasts according to arithmetic grading normally increase from one size to the next by 1/3 inch overall in length and 1/4inch in the joint girth. This means 1/6 inch width grade for upper patterns and 1/12 inch for bottom patterns.

When hand grading, many ignore this difference and grade proportionally, based on a 1/3 inch increment for the overall length. By marking off the lasting allowance and using the feather edge line to ascertain the width grade, a good enough result is obtained for grading up to three sizes above or below the model size. This is because the relationship between the length and width of the pattern is normally near enough that needed, to make proportional grading the same as that used on the lasts. However, if necessary, the feather edge line can be adjusted at the joint, so that it measures down from the crease (centre) line, 1/4 of the overall length of the standard (minus lasting allowance). These will both restrict the lasting allowance and give the correct 1/12 inch (1/6 overall) width increment.

Apart from the general restrictions further restrictions are necessary for the various parts of the pattern that have to remain a constant length or width throughout the size-range.

Examples of this are folding or underlay allowances, strap width (to fit standard buckles), lasting allowances and back heights which are restricted to 1/16 inch increase or decrease from size to size.

With practice the designer can produce a "graded" pattern using the above method very quickly and as long as the design lines have all been carefully balanced, the shoe should have all the lines and proportions of the original sample (BORDOLI, 1938).

RUSSIAN METHOD

The main principle of the Russian technique is that all length last measurements are changed proportionally to the last bottom length. Girths, widths and heights are changed proportionally to the ball joint girth.

However, as mentioned above, we should note that the principles of last and pattern grading are very similar in Russia and in the UK. The difference is, first of all, in the numeration technique and different increments between sizes and fittings. It means that the interval between sizes is 5.0 mm and the interval between fittings is 8.0 mm for casual footwear and 6.0 mm for high-heeled shoes and for children.

Although the analysis of correlation coefficients showed that when increasing the last length to 10 mm, the ball joint girth should increase by 6.6 mm, joint width by 2.7 mm, seat width - by 1.7 mm but not by 6, 2, 1.5 mm respectively. But when grading by hand many ignore this.

The **basic differences** between Russian and the UK grading methods are listed below:

Although the lasting allowance should be constant there are grading methods not marking it out as its width when grading changes proportionally to the last ball joint girth and is within limits of technological norms.

There is a grapho-analitic method of the last sections grading in fittings with the bottom shape standardised, based on the common regularities of the foot and last measurements changing.

3D last surface grading is made according to the master forme length, when the longitudinal axes is a geodesic line and transverse axes are dropped perpendicularly from the tread point.

Usually at the practice of pattern grading it is used the upper length measured on an axis of symmetry of the pattern instead of geodesic line that also deforms the result.

When pattern grading it is necessary to take into account that lasting, folding and other allowances should be constant. To solve the problem the technique offers either to grade marking out the allowances, or to recalculate the increments.

The triangle method allows to grade pattern parts separately or to make pattern cutting after the grade has taken place.

In accordance with Russian State Standard 3927-88 lasts of all sizes in a set are to have identical heel elevation. It allows heels of one height to be applied to the whole range of sizes. However, such construction leads to a strong distortion of the toe spring and to the general distortion of the footwear appearance since footwear of smaller sizes will have larger relative heel-height. At attempt to limit the toe spring, disagreement arises not only with pattern grading system as in the previous case, but also with designing unit moulds for insoles because the waist curves are different.

To decrease the number of correcting operations in the last grading in the case of similar restrictions western techniques use a system of sub-models and grouping the sizes. American last grading system assumes not only uniform heel-height and toe-spring but also the same width of the bottom, the same shape of the back part, identical waist line, identical dimensions of cross-sections for three continuous fittings and identical parameters of a top cone plane for all sizes of a set. There are also the techniques of last manufacturing with uniform heel-height.

However, from the point of view of aesthetic appearance of footwear, in order to prevent discrepancies in grading lasts, patterns and tooling-up it is recommended to carry out straight grading without restrictions.

For the purpose of grading process automation in Russia the semi-automatic device was invented, it works on the same principles as pantographs. For machine grading the specified increments should be calculated. There are different methods of doing this.

The analysis carried out in the Saint-Petersburg State University of Technology and Design (SPSUTD) shows that optimum parameters when grading are given by the method of firm "ALBECO". Results of accounts based on this technique give the greatest economy of the hide.

The technique recommends to calculate the length increment on a symmetry axes of the style without account of lasting allowance The width increments take into account the last ball joint girth, upper width in the ball joint and the style width with lasting allowance.

In the grading machine there are also available special correctors permitting change to increments of separate sites of a pattern preserving the basic set-up. Necessity of such corrections is conditioned by that at direct grading very frequently the form of details of extreme numbers of a series is deformed and smaller numbers are to last difficulty whereas larger ones have too large surplus of a material on lasting allowance. The width increment of the last bottom pattern reaches 1,5 mm, and the length one - reaches 6-7 mm.

Arithmetic grading is commonly used in Russia as in the UK. Geometric grading when the increment per size and/or width of any dimension is specified as a constant percentage of the dimension has large technical advantages but has not gained recognition in the industry. First of all, because of a difference in intervals between the sizes that complicates the footwear fitting. Secondly, to serious lack of the geometrical system they concern significant change of the absolute measurements of extreme numbers of footwear in a set comparing with their change when arithmetic grading. These changes result in infringement of the proportionality of the footwear and the feet of the population.

Nevertheless, the most accurate results and time and money savings could be achieved by use of CAD grading means.

3.4 Relationship Between Foot and Last Shape

All people expect footwear to be comfortable, well-fitting, and fashionable. To ensure comfort provision must be made for the freedom of movement required by changes in foot shape. Good fitting implies a clinging sensation on the foot, with the absence of unsightly folds when the boot or shoe is in a normal position. "Fashionable" means that the footwear conforms to a certain outline, irrespective of the natural shape of the foot. Utility is another condition to be satisfied, chiefly by the materials in the footwear and by the form of its construction. In order to satisfy all these conditions the last model maker must depart from the actual form of a foot as revealed by its specification and measurements. Though these forms are the basis for a model last, they need to be modified in different ways.

This will be presented in chapter 5 of the thesis in more details. However, listed below are basic differences in foot and last shapes and rules to be taken into account at proper last designing.

- **Last feather edge;**

In handicraft manufacture the feather edge (a line crossing last lateral surface with the bottom that connected to the technological features of the footwear manufacturing from flat details) served as a checked reference on which a piece of the leather nailed to the bottom was cut. At present the bottom parts are orientated concerning the last feather edge. In the foot, the bottom smoothly transfers into a lateral surface and from the point of view of the footwear comfort the feather edge in the last is superfluous.

- **Last cone top part is necked ;**

The back part of the last considerably differs from the foot form (it is necked for better embracing the foot by the footwear top part). Such designing in wearing provides good stiffener bearing against the foot without its pressing at the expense of increasing the back part measurements during loading by the weight of the body.

- **Toe spring;**
- **Heel elevation;**
- **Length and shape of the last bottom;**

When considering the length of the foot and footwear it is obvious that footwear ought to be longer than the foot for so-called toe allowance. According to the last designing principles it could be of two kinds: allowance calculated by taking into account medical recommendations - minimum allowance - and fashion trends - decorative allowance. Functional allowance for lasts for lady's casual footwear and other is *10 mm*. This always provides available free room not limiting functional movements of the foot of changing the foot length caused by both external and internal reasons. Additional allowance is applied to the toe shape of footwear (its width, height) and changes from *0* up to *25 mm*, in some cases even longer.

Detailed researches have shown that functional allowance should not be identical for the lasts of different size groups, and also for the lasts of various lengths in identical size groups. In the footwear for adults growth of whose foot in length is completed, functional allowance should be 2,5-3% of the foot length (CHENTSOVA, 1974). Such allowance provides in exact measure free room in footwear, necessary room for lengthening the foot during movement ("apparent" increase of the foot length), and also for the foot lengthening under load, daily changes etc. Dependence between the length of the foot L_f and last L_l is expressed by the formula:

$$L_l = L_f + P_1 + P_2 + P_3 - S, \qquad (3.1)$$

Where P_1 - length allowance for foot increase during walking;

P_2 - allowance for average growth of the foot length during a half-year;

P_3 - allowance dependent on the shape of footwear toes;

S - shift of the foot in the seat.

According to allowance classification the sum $P_1 + P_2$ would be a functional one, and P_3 additional aesthetic allowance. The formula has universal character and relates the general principles of last length definition to the growing foot. Presence of the allowance taking into account a gain of the foot for the half-year period, is explained by that the footwear for children and teenagers is bought usually for so-called "on growth" period, and also by that more often half-year is maximum term of such footwear wearing.

- **Smaller girth parameters;**

Similarly to that the foot length is impossible to consider as length of the last the ball joint girth is impossible to identify with its fit. The fit of the last is its girth in *mm*, measured in a place of measuring the metatarsal. From the internal side of the last the point of measuring the fit corresponds to a point of first metatarsal (metatarsus-phalangeal joint of the first toe), from the outside - to the fifth joint. The children's footwear is produced a little wider in comparison with the foot, but for adults on the contrary a little bit closer (for smaller fits).

Bulk production requires precise definition of consumer demand for sizes and fittings of the footwear. In such situation intuition and experience of the shoe-men making footwear on measurements for individual customer is insufficient.

The complete range of footwear should be developed on a basis of sufficient results of mass foot measurement. Correct usage of the results of mass foot-sizing when determining the last fittings probably is possible only on the basis of additional information, assumed from detailed researches of the feet. Anatomic structure and physiological foot functions define the pressure rendered on it by the footwear uppers (as it is shown by rheographical research).

The foot measurements taken in weight-on condition are not maximal. If these measurements are adjusted only on amounts describing allowable pressure then in dynamic conditions the foot will be subjected to larger pressure, that will negatively affect its functions. Such pressure can cause narrowing blood vessels and present difficulty of correct circulation of the blood. To get rid of these measurement results should be twice adjusted:

- The foot girth taken when measuring with weight-on ought to be increased by a gain of the foot in dynamic conditions;
- The obtained result is necessary to reduce for the value measured at rheographical researches.

By results of rheographical researches it has been established the allowable limits of reduction of the foot ball joint girth (compression of the foot) in percentage of measure results taken with weight-on. Such compression of children's feet in the age of 1-6 years is *0%*, in 7-8 years - *1,58-1,59 %*, 11-12 years - *2,35-2,40 %*, adult feet - *3,20-3,43 %* (FUKIN et al, 1987).

There is less of a concern the feet of boys and men, but higher - for the feet of girls and women. It is explained by that feet of women have larger thickness of fat tissue, hence, they are less sensitive to the compression.

Using results of researches of scientists of different countries, it is possible to define the coefficient of transition from the foot ball joint girth to the last fitting. The coefficient characterises dependence between girths of the foot, last and footwear in ball joint.

$$K_{bj} = 1 + (G_1+G_2 - q)/G_{bj}; \qquad (3.2)$$

Where - G_1 - increase of the foot girth at walking, *mm*;

G_2 - increase of the foot girth during a half-year (during growth of the children's feet), *mm*;

q - allowable compression of the foot, *mm*;

G_{bj} - average foot girth in weight-on position.

Knowing the coefficient K_{bj} it is possible easily to pass from the foot ball joint girth to the last fitting using the formula:

$$T_l = G_{bj} K_{bj}, \qquad (3.3)$$

where T_l - the fitting of the last;

G_{bj} - ball joint girth of the foot measured in weight-on condition.

The problems considered till now concerned only the relationship between the basic measurements of the foot, lasts and footwear. Dependence between other individual dimensions is reflected by constructive coefficients to depending from proportions of the foot measurements. So, at designing the last bottom pattern being its "skeleton" they take into account proportions between the measurements of the foot and the last. The analysis of principles of last designing shows that the last width in ball joint is *33-36 %* of its girth in ball joint while this relation for the foot - about *40 %* (FUKIN et al, 1987).

As operation has shown the narrowing footwear in ball joint does not influence its comfort but considerably improves aesthetic look. In opinion of many medics, such narrowing protects the foot from lowering the transverse arch, i.e. from development of the metatarsalgia. It has significant importance since the life of modern person described by large activity of movements and frequently by work in standing situation, results in significant static-dynamic loading of the foot, exceeding its serviceability. Infringement of balance in given area can cause foot diseases and deformities. In such situation the footwear can promote improvement of foot functions correcting its reactions on the adverse factors.

All individual measurements of the lasts and the footwear are subordinated to two measurements: length and fitting (ball joint girth) or length and width. Defining the individual width measurements of lasts and footwear using its width in ball joint in view of coefficients of a ratio of the sizes of the foot and footwear, on a basis of foot anthropometric researches comes to light the following dependence: the sizes of the lasts and footwear are always less than the similar sizes of the feet (except the length).

- **Last toe part shape**;

Although it is designed according to the fashion trends, of great importance is also to provide the toe shape of the last corresponding to the average foot shape. It protects the foot from toes deformities - hallux valgus and etc. with increasing the first and the fifth metatarsal heads.

Chapter 4. CAD/CAM Systems for Footwear Design and Grading

Introduction

In two decades of progressive development CAD/CAM technology (Computer Aided Design and Computer Aided Manufacturing) has made great strides to the point where it is now possible for a shoe designer to work on the screen just as he would at a desk, with all the additional benefits of stored data, instant modification, automatic grading, costing profiles and interchange between 2D and 3D for effecting the design-manufacturing link-up.

It is much more user-friendly than ever before, it is highly flexible, costs have come down and systems work in ways that are much closer to the shoemakers needs. As a result, they give shorter production time, improved accuracy, more reliable reproduction of the design intent, and higher repeatability in a series of moulds.

4.1 Methodology

4.1.1 History of CAD/CAM

The 1980s saw an explosion in the development and use of computers in all walks of life. Industry was quick to make use of the low cost/power ratio of microcomputers, in particular, and the footwear industry was no exception. Probably one of the earliest applications of computers in shoemaking was in computer aided design (CAD). Development of CAD/CAM systems in basic was determined by common process of developing computer techniques.

In the late 1960s computer grading was available but the level of technology at that time meant they were slow, expensive and had limited graphics capability. It was not until the 1970s that the first viable CAD system - the Gerber Camsco Apex package - became available. Computer power was still expensive, however, and few companies were able to make the investment. Today 2D footwear CAD systems for grading and pattern engineering, such as the GerberMicro FDS Grading system, have become almost commonplace.

Reduced hardware costs have meant that a turnkey system can be obtained for a reasonable cost and, compared with earlier systems, are far more versatile, faster and more user friendly.

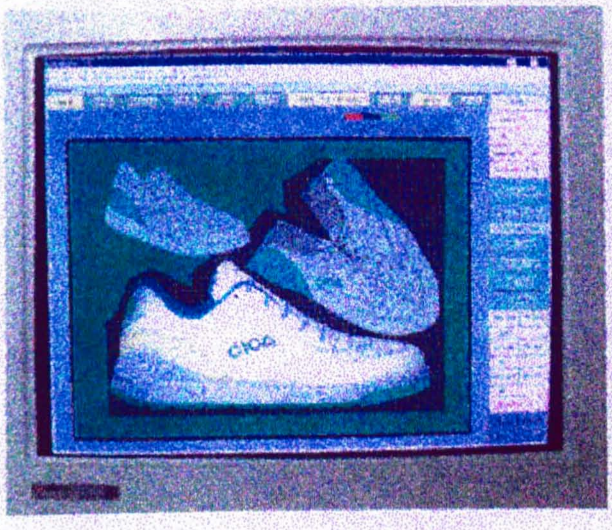
However, as the systems were orientated, as a rule, on pattern engineering, they in methods of the work simulated "traditional for a designer" principles of work at a factory. Thus they used last measurements obtained in a traditional way.

Nevertheless, a lot of improvements have been made in the functionality of systems. Gone are the old piece grading methods: all systems now use the shell or line grading approach with its improved speed and integrity (Fig. 4.1c – CRISPIN CAD System), a modular approach and a range of utilities. Much emphasis is now being placed on designing and producing footwear tooling from CAD data and suppliers offer a variety of modules for the design of autostitcher pallets and punching dies (Fig. 4.1b - CRISPIN CAD System).

In the past, neither hardware not software was sufficiently developed to make 3D CAD attractive to the majority of footwear manufacturers. The computers were available at a reasonable price but they were not capable of handling the complex mathematics and large quantities of data with sufficient speed. Now the situation has been changed. 3D CAD is available for style development and visualization and for the design and production of 3D tooling.

4.1.2 Necessity and application of CAD/CAM

It was a truly remarkable breakthrough and one wonders, with all the benefits of creating new designs and immediately putting them into sample, even short-run commercial production, why it has not yet been widely adopted in shoemaking. Most CAD/CAM applications are for pattern engineering only.



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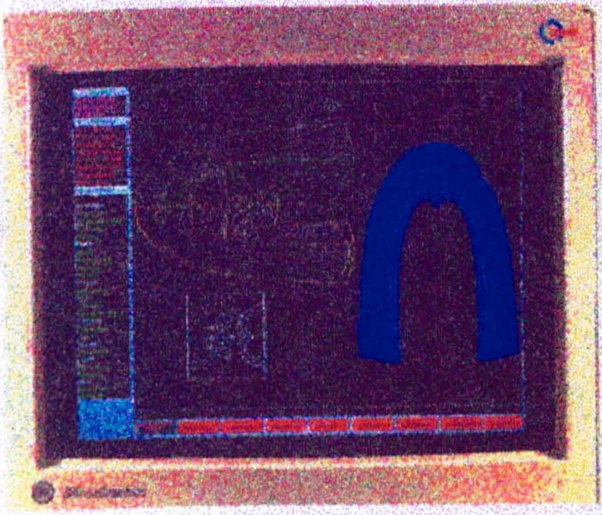

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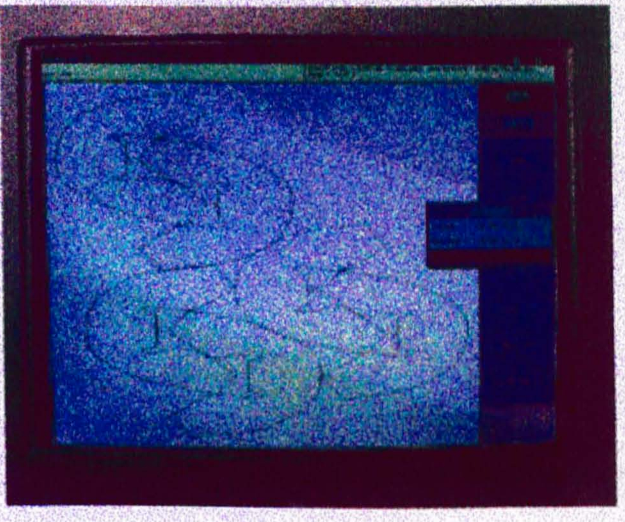

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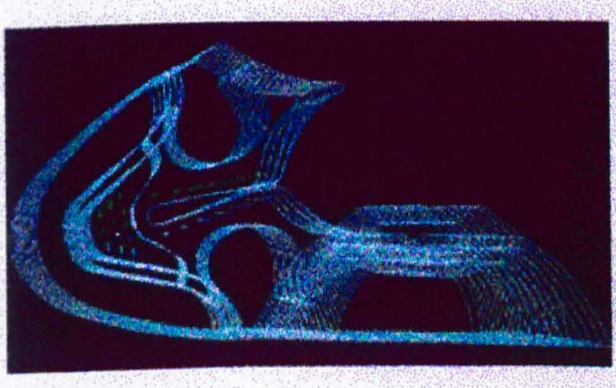

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Fig. 4.1 Features of available CAD/CAM systems

Cost and conservatism of the shoe industry are most probably relevant factors, but new generation of designers, stylists, pattern engineers and footwear technologists, who are fully conversant with computers, could well be the catalyst that will see CAD/CAM become the practical everyday tool it deserves to be (THE FUNCTIONALITY OF 3D CAD/CAM, 1993).

Installations, it is true, are still numbered only in their hundreds rather than thousands, and relatively simple pattern engineering applications have found most favor. But this situation could change. One factor to the benefit of CAD/CAM is that quick response is now the order of the day with a galaxy of styles on offer to clients rapidly narrowed down to chosen ranges and put into production fast. This is an ideal scenario for CAD/CAM (CAD/CAM UPDATE, 1995).

CAD producers are designing modular software systems (NEW DEVELOPMENT AT SHOEMASTER, 1995). The modular approach means that the software is split into units to do certain operations. This has advantages for both supplier and customer. It allows the purchasers to buy only the modules they require and not the whole package, cutting the costs of both the system installed and the training required. Extra modules can be added when required. The advantage to the supplier is in the increased manageability of the software, which leads to improved quality.

The handful of companies in Europe and North America that pioneered the development of CAD/CAM in shoemaking are mostly still around in a variety guises and they have been joined by many newer names in Europe and Asia, which between them provide systems for virtually every aspect of shoemaking (LECTRA FOCUS ON CAD/CAM FOR SHOEMAKING, 1995).

4.1.3 Typical CAD/CAM systems and their common features

There are the following main shoe CAD systems:

SHOEMASTER ShoeDesign from Clarks;
CRISPIN CAD System from USM;
PADSY + TASC from Procam Systems;
SHOEMAKER from Gerber Systems Technology;
MICRODESIGN I&II, FDS Grading from MicroDynamics;

DUCT from Delcam;

ROMANS CAD from Lectra Systemes;

SHOECAM from Internationale Schuh Maschinen;

CALIGOLA from Comelz;

SHOEDESIGNER Cadis, PERSONAL Cadis from Iselqui.

DIGITOE from Computerized Footwear Systems (GORDEYEVA and ROOT, 1996).

Many of today's users operate in a very straightforward way: they use the CAD/CAM systems not for design but mainly to bring the grading and fast cutting of patterns under their own control, with the design and prototype development of shoes being carried out by traditional means.

CAD vendors supply comprehensive 2D grading facilities which enable users to perform quite complex grades relatively easily and quickly. Developments in recent years, however, have made 2D systems more attractive for design work. With 2D sketching modules now available from the major CAD vendors, the stylist can quickly produce a serviceable sketch and then add color and texture. Modification to lines, color or text can be carried out very quickly and the drawings are easily transmitted, in color, from one computer to another. It is an excellent medium for communicating design ideas (THE IMPACT OF TECHNOLOGY ON PRE-PRODUCTION ENGINEERING, 1994).

Three dimensional systems allow designers to sketch styles on a full 3D representation of the last on the screen. The 3D last surface is then flattened within the system to allow 2D patterns to be created (Fig. 4.1a – Shoemaster System, Fig. 4.1b – CRISPIN CAD System).

An alternative method, for stylists who prefer to handle a 3D object, is to design directly onto the last surface, or onto a plastic vacuum form of that surface (THE NEWSLETTER, 1995). This design can then be digitized into the CAD system for the subsequent steps.

Most 3D systems offer a 'windowing' facility to allow viewing from several angles simultaneously. This is a useful feature during 3D design, as lines can be drawn or modified on the last surface in one view and the changes can be seen simultaneously in the other views and vice-versa. Some systems offer a 2D option in one of the windows showing the standard with the associated style lines being modified (CAD/CAM UPDATE, 1995).

3D rendering is becoming popular for visualizing finished style.

The latest workstation hardware is being used for the graphics driving capabilities, allowing 16.8 million colors on screen. 3D style lines are imported from the designing module and a photo-realistic image is produced on-screen by the use of special functions (Fig. 4.1d – Shoemaster System).

These include the build up of a library of textures and shades with a range of reflecting values. Also, scanning hardware and software allows material textures and designs to be captured and wrapped around the style. Simulated backgrounds with reflections and shadows can be created to add to the presentation.

Systems are becoming integrated so that information can be transferred from a single central reference source to wherever it is required for pre-production and production operations; this speeds up the process and reduces the chances of inaccuracies creeping in.

Early use can be made of computer modules for materials and labor costs, lay planning (Fig. 4.1e – CRISPIN CAD System) and style specification sheets. These do not require development shoes to be made - they simply use the CAD data. If the shoe appears too expensive for the target market, it is possible at this early stage to adjust components or operations to meet the target (THE IMPACT OF TECHNOLOGY ON PRE-PRODUCTION ENGINEERING, 1994).

Development in computer hardware and relational databases now allows a vast amount of data to be stored and retrieved quickly and economically, including diagrams and photograph images; it can be information about styles, samples, lasts, components, trims, costings, employees and customers; the information is designed to be as visual as possible and scanned images are used where appropriate. The systems allow highly detailed and accurate product specifications and design descriptions to be produced at an early stage.

4.1.4 Last modeling functions

Before styling can begin on a 3D CAD system, the required last surface must be digitized into the system. As lasts are freeform shapes, they have no lines, points or planes of symmetry - they can not be described by simple geometric units. The last surfaces are input into the CAD system by means of 3D digitisers (Fig. 4.2a – CRISPIN CAD System). The most common types, because they are relatively cheap, are manual digitisers, advocated by MicroDynamics, Clarks and Atom & Vicam (CAD/CAM SPREADS ITS WINGS, 1995).

Approximately 300 co-ordinates are taken from a pre-marked last surface in a known order using a hand held pointing device (Fig. 4.4a – Shoemaster System). These co-ordinates are taken to produce either a patchwork or a series of vertical and horizontal stripes. Most of the manual digitizers also allow style line digitization from the last surface.

Once the digitized surface has been captured and processed, it can be displayed on screen. This is usually as a splined patchwork of the surface points or a realistic shaded surface (Fig. 4.2c – CRISPIN CAD System). This surface can be rotated and viewed from any angle. Style lines can be drawn onto the last surface using a mouse or stylus.

Next step is flattening - a flat representation of the top surface area of the last (Fig. 4.1b - CRISPIN CAD System). Manual flattening is a skilled task requiring many subjective decisions. To enable CAD systems to duplicate this, a variety of mathematical algorithms that take the 3D mathematical surface and flatten it to 2D have been developed by the CAD designers. The flattening of a design is a crucial part of the operation. It is impossible, due to the shape of a last, to flatten its surface without creating distortions. The critical element is to introduce this necessary distortions where the upper materials and the lasting process will be able to cope with them (THE SHOEMASTER USER MANUAL, 1995). User interactive last shell flattening is currently being adopted by the CAD producers. This offers both flexibility and control over the process and enables companies to apply their own factory conditions.

A common method of flattening the last surface is to define flattening axes. They are user controllable and dependent upon the style of the shoe and the type of last being used. The flattening axes are usually lines of least distortion from the throat of a style to the heel curve (CAD/CAM UPDATE, 1995). A point to watch here is that with flexibility comes the problem of operators choosing inappropriate flattening.

Some of the 3D systems now available offer surface creation and modification facilities. This means modifying last surfaces or creating and modifying heel and sole units. Last modification can take two forms. Firstly, there is last blending, where two digitized lasts are combined to form a third (Fig. 4.3a,b – Padsy + Task). It involves taking the backpart of one last and the forepart of another and defining a blending region between the two. Usually, multiple views are shown to help the user with the orientation of the lasts.

The second modification method involves changing a single last. Surface points can be selected and moved, with the software then blending that point into its local area. Again multiple views are used, allowing the user to see the modification effects from different angles simultaneously. This method allows walled lasts to be created. The splining element is removed from the relevant surface points to produce a sharp corner rather than a smooth curve.

3D grading creates a range of 3D mathematical surfaces - from the original digitized last - in the CAD system. Grading can be arithmetic, geometric or to user-specified rules. As with the traditional methods of grading, co-ordination can be introduced to restrict heel heights, for example. The benefit of 3D grading over 2D grading is that the resultant patterns are more accurate. Each last in a range is flattened rather than just the model, eliminating the compounding of flattening distortions that occurs with 2D grading. This is beneficial only if the graded last data is actually being used to produce the physical last. Group grading must take place in 2D, with the style lines being mapped back onto the graded last.

If a new last has been created within a CAD system, then some form of assessment should be carried out to determine the characteristics of the new last (Fig. 4.3c – ShoeMaker System). Last surface development is a subjective exercise. Modified surfaces need to be manufactured and assessed manually. After this, further modifications

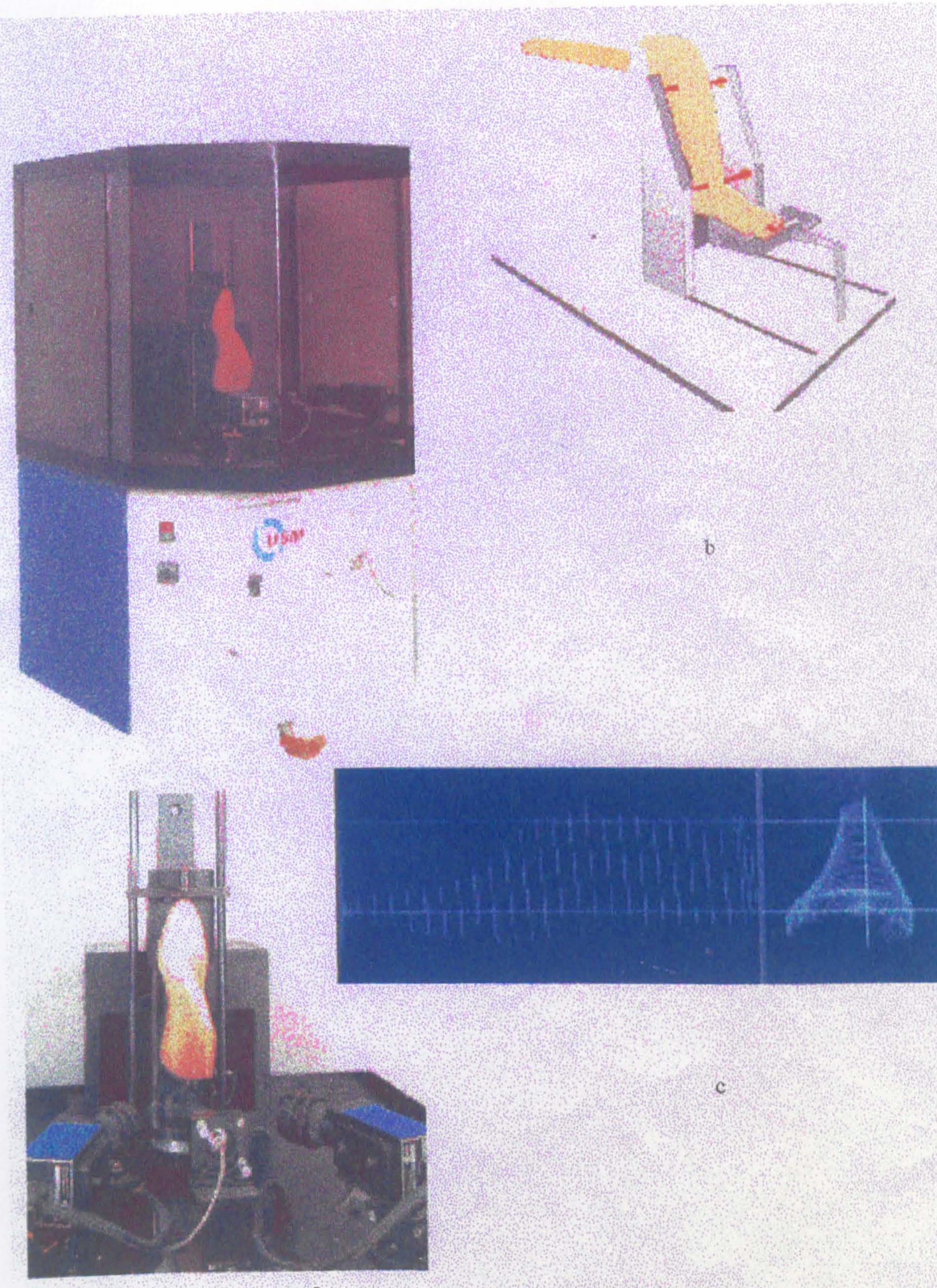

Fig. 4.2 Last surface digitizers

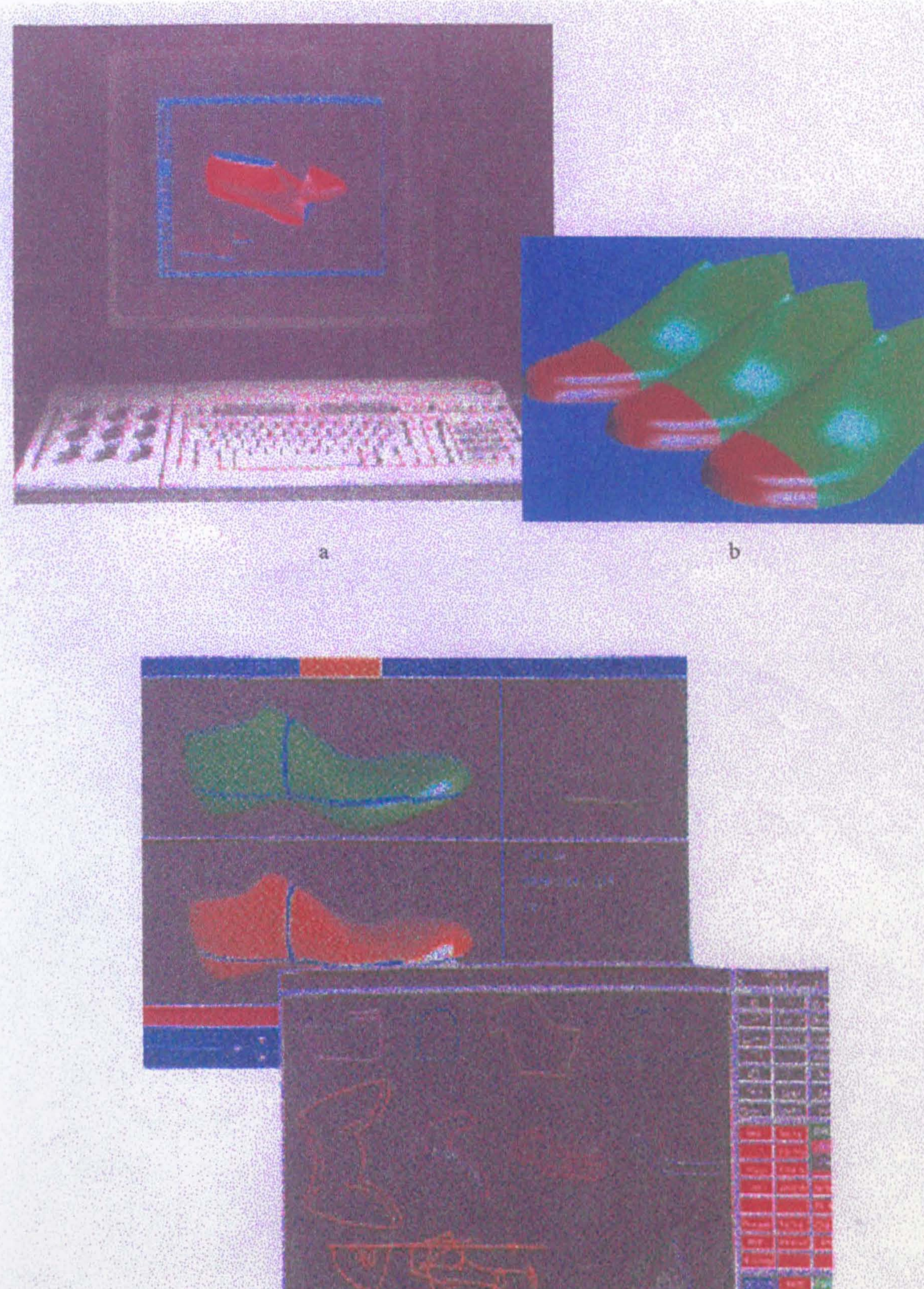

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Fig. 4.3 Last surface modifications

may need to be made. SATRA has developed a computerized package based on extensive experience in manual assessment (Fig. 4.4c - SATRA).

The various measurements can be made by the system and compared with existing guidelines within the system allowing a report on the fitting characteristics to be produced (CAD/CAM UPDATE, 1995).

As well bottom parts can be created and modified in a number of 3D systems (Fig. 4.1f – Shoemaster System). Usually, a generic heel, for example, is created by entering a series of parameters such as heel height, top-piece diameter and seat angle. This is displayed and modified by adding, deleting and moving surface points until the desired heel unit is created. Although sole units are more complex than heel units, they are treated in a similar way. 3D last bottom data is used as the basic element, and again, a series of parameters are entered to create a base unit for manipulating into the desired shape.

Some CAD systems allow a last or sole surface to be built up from profiles created in 2D CAD systems. Some systems offer the creation of 3D elements on the sole, such as cleats, studs and logos. These units can usually be shaded and rotated to allow assessment of the design (THE FUNCTUONALITY OF 3D CAD/CAM, 1993).

With the 3D design systems it is very useful after modifying and finishing the last design to have possibility to output instructions from the CAD system for machining the newly designed last under numerical control on a milling machine or a lathe. An important development in this context is the "Jones & Vining" "Compu-last" system for last manufacture which comprises three modules: digitizing, grading and machining with a variety of data links with shoemakers' CAD systems.

As the CAD systems also include digitizing and grading facilities, as well as design, there is a choice of routes open to shoemakers in creating a new last. Because the last is then machined accurately under numerical control and is consistent with the shape data in the CAD system, it is possible to develop shoe designs and tooling before the last physically exists and have confidence of compatibility (THE IMPACT OF TECHNOLOGY ON PRE-PRODUCTION ENGINEERING, 1994).

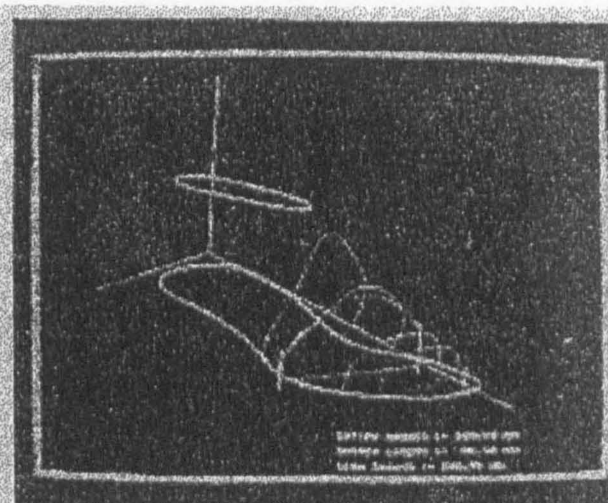


Fig. 4.4c Computerized package
for last surface assessment

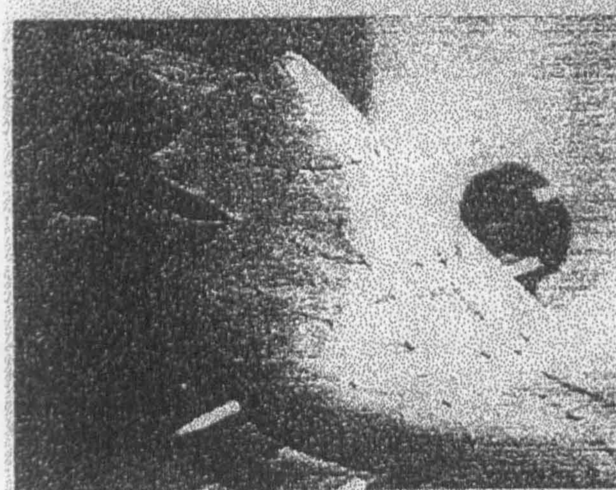


Fig. 4.4a Pre-marked last

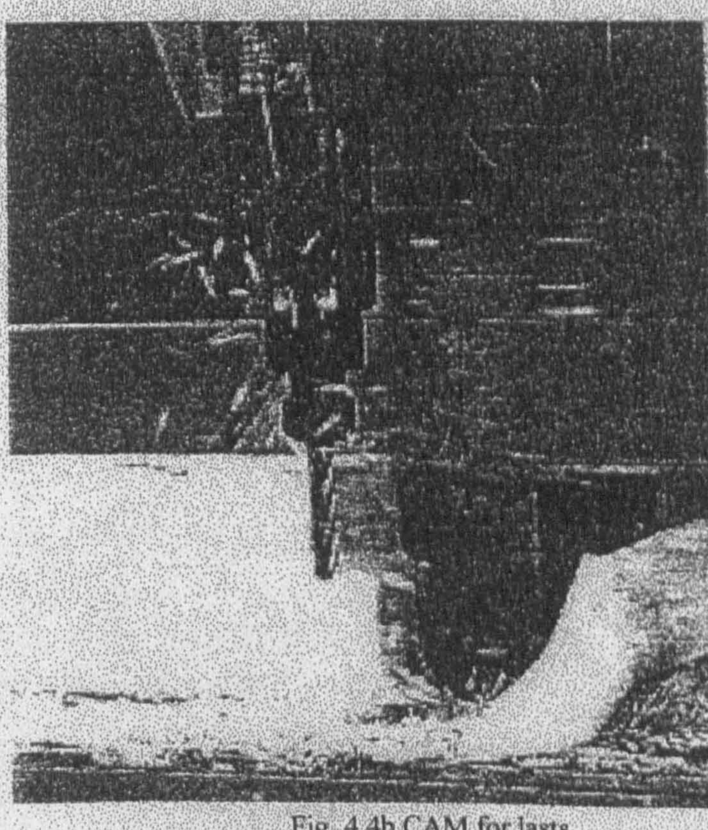


Fig. 4.4b CAM for lasts

CAD for last takes two forms: last milling and last turning (Fig. 4.4b – Shoemaster System). Last milling is usually done on a 3-axis machine and is slow not suitable, therefore, for a company needing to produce large numbers of production lasts. Also, the work-piece needs to be inverted to allow the two sides and the bottom to be machined. "Desma" are producing their own metal formers for moulds, in-house.

The second option is last turning. Mentioned above "Jones & Vining" have taken conventional last turning lathes and retrofitted to allow NC data to be accepted. This method can produce the required last much more quickly than last milling. The disadvantage of turning compared with milling is that the toe and heel dogs need to be removed after production - a problem currently being addressed (CAD/CAM UPDATE, 1995).

Orthopaedics is another area where the manipulation of 3D CAD surfaces can be of significant benefit. Some companies are working towards developing software to produce orthopaedic footwear with an element of fashion styling in them.

Digitoe from Computerized Footwear Systems could be noticed as the latest development in the area. Its object was to adapt 3D CAD/CAM technology to bespoke footwear. They suggest the total solution from scanning of the foot to milling the last and producing the shoe. The company claims it has developed software for designing and modifying a 3D last and also an alternative to conventional last turning methods (DEVELOPMENTS IN COMPUTER-AIDED DESIGN FOR FOOTWEAR, 1996). However, their claims have not been proven yet.

According to the above, the general requirements for a 3D CAD system at the stage of last surface creation and modification are as follows:

- Accurate, totally definable 3D digitized last datum must be obtained. The bottom of the last is essential for most of this work and must be captured at digitization.

- The ability to modify a last surface in a variety of ways and the ability to measure those modifications is needed. A last surface must be viewed from several different angles simultaneously to give the user the necessary control.

- The ability to grade in 3D is required. If production lasts and units are needed then this function is essential.
- It should be able to use this last data as the basis for creating sole and heel designs.
- It should have links to 3D computer aided manufacturing (CAM) outputs allowing CNC tool-paths to be generated.

The main common features of available CAD/CAM systems are:

1. Upper sketching on the last;
2. Instant modifications of designs;
3. Viewing of designs from several perspectives and angles simultaneously;
4. Flattened designs transferred to Pattern Engineering;
5. 2D designs can be reverse-engineered back onto the last;
6. Texture and color adding, including highlights and shadowing;
7. Automatic grading;
8. Facility of systems to store and retrieve data quickly and economically;
9. Thickness of upper components is fully adjustable throughout;
10. Design of soles and heels;
11. Tool-path generation for machining prototypes;
12. Data generation for mould-making.

This is not an exhaustive list of all that is available but does show the general features.

4.2 Conclusions

Have studied all features of available CAD systems, it is clear that :

- As the systems are the following stage of developing footwear technology after hand-operated and mass manufacturing they combine advantages of hand-operated method: an opportunity of complete design of the form and contours of footwear by one person and taking into account individual feet, and factory method: an opportunity of decreasing labor intensity at the expense of automating manufacturing.

- Commercial CAD/CAM systems provide a wide range of features and consist of multiple software modules so that the customer has a good choice according to the task. CAD/CAM has become a beneficial everyday tool enabling rapid change of assortment and resulting in significant savings in materials and labor and producing better shoes.

- Weak use of 3D systems in shoe manufacture is marked in comparison with cheaper 2D systems. It is connected to the fact that the basis for 3D designing - a last - is still made manually.

- All systems model the last but no system is able to create the 3D last surface directly from the foot measurement or on-screen from minimum foot datum.

- Few systems can modify the last data. Some engineering software such as DUCT5 from DELCAM used by USM have extensive capabilities to modify the last surface and then machine it. Clarks are persuing this field. Digitoe claims they can do this.

- Some systems offer facility of selection the most appropriate last for particular foot measurements.

- "Padsy + TASC" is close system to the task of the thesis because of PC's basing and scanning the foot. But it only can chose the last from the library or blend the two lasts to create the new one.

- Curve and surface design in CAD/CAM application still has many unresolved issues.

- There are no optimum last measuring devices. This means that all systems use manual or laser digitizers which either are very labor-intensive and inaccurate or collect a lot of data that has to be reduced so it can be surfaced doing this the critical sections are lost and also the feather edge is not defined well.

- Now systems have ability for CAD data to drive manufacturing equipment, for example automatic stitching machinery.

However weak use of CAD/CAM systems in the industry proves that it is not so beneficial as could seem and all the advantages have no significant meaning in comparing with those that could be achieved if to automate the processes of the last designing and production. This confirms efficiency of creating direct computer last design system.

The greatest benefit one could have from employment NC-means. Recently occurrence of electronic foot-sizing devices and NC-machines for last manufacturing is recently marked. It creates the preconditions for generating CAD/CAM system on the basis of last synthesis with regard to foot data.

Chapter 5. Methodology of last design according to foot data

Introduction

As far as is known, the shoe last is not a precise copy of a foot, hence, for creating new models of shoe lasts it is necessary to develop a transfer method from the average foot (or from individual foot in particular case) to the last on the base of available data. However, the last shape is highly complex and unknown and, as previously discussed, the particular complexity consists in absence of precisely developed and formulated rules, formulas or coefficients that allow foot measurement data to form a high-grade last. The last datum relationships are also unknown. Besides, even published techniques most commonly do not correspond to the reality.

With the purpose to invent the last design technique much research work has been accomplished to reveal the basic last parameters influencing its shaping in greatest manner. The work carried out is listed below:

- literature that relates to usual practice of last designing by hand using foot data was studied;
- leading shoe last designers, shoe stylists and sports physicians were interviewed;
- analysis of scientific reports of last 30 years and interviews with orthopaedists of Saint-Petersburg Factory of Orthopaedic Footwear and Saint-Petersburg Institute of Orthopaedic and Prosthetic Appliances were conducted, which have confirmed the absence of precise methodology of last designing;
- separate methods of different last elements designing with regard to anthropometric data that are used in Russia and in several countries in Europe were investigated and tested;
- great number of feet and ready lasts were measured to define the average foot and to study the last shaping;

- experiment of measuring the individual foot and designing the last for the latter was carried out that reflected rationality or, on the contrary, discrepancy of particular techniques of the last elements designing;

- On the basis of materials studied and experiments conducted the fundamentals of last designing on the basis of anthropometric data were elaborated.

5.1 Specific methods and constraints of existing last design

5.1.1 Fundamentals of last designing

The research of methods of a shoe last designing has revealed an absence of the uniform approach to modelling. However, it is safe to say, that traditional techniques of manufacturing the model shoe last (KALITA, 1988; CHENTSOVA, 1971; HOLEVA et al, 1981; FOOTWEAR LASTS. RUSSIAN STATE STANDARD No 3927-88, 1990; STEPANOV, 1960) assume development of a set of flat patterns (a bottom pattern of the last, longitudinal-vertical section, about nine transverse-vertical cross-sections in the main anatomical points of the foot). At the same time, Russian Standard for lasts (FOOTWEAR LASTS. RUSSIAN STATE STANDARD No 3927-88, 1990) rations only girths of two cross-sections (***0,68/0,72L*** and ***0,55L***) and width of the bottom in sections ***0,68/0,72L*** and ***0,18L***. Proceeding from these data usually received on the base of a plantogram and a plaster cast a last designer produces a last sample manually according to the patterns; the sample hereinafter serves as a basis for designing footwear parts and tooling.

All available methods of the main last contours and sections designing may conditionally be divided into ***graphic*** (with use of the graphic information of the foot - plantogram, projections and contours of the sections), ***calculated*** (using formulas of recalculation of the foot parameters into the shoe last parameters) and ***combined***.

For designing individual last the method of the bottom designing based on plantogram of the foot is preferable, as the plantogram gives the comprehensive information about the particular foot morphology, whereas calculated methods are intended, basically, for constructing a last for an average foot.

It should be noted, that various techniques of anthropometric measurements suggest different variants of leading the foot length axis often conterminous with the longitudinal axis of the last bottom, that is defined by a type of a last designed and a degree of the foot supination. So, the axis can take the following positions:

- Tangent to an internal contour of a dimension (ZIBIN, 1982; LIOKUMOVITCH, 1984; ZIBIN, 1949);
- Tangent to a print contour from the internal party (FUKIN, V.A. et al, 1987);
- Line going through the center of the last back part and between the first and the second toes (LIBA and FUKIN, 1983; FUKIN et al, 1987; FARNIEVA and NURDELGIEV, 1982);
- Line going through the center of the back part and between the second and the third toes (KOMISSAROV, GOLAND and PETRENKO, 1994; KOCHETKOVA et al, 1991; MAKARICHEVA, 1972; FUKIN and ZIBIN, 1966; DEFINING LAWS OF LADIES FEET SHAPING WITH ELABORATION OF METHODS THEIR MATHEMATICAL DESCRIPTION, 1987);
- The print bisectrix (CHENTSOVA, 1971; FUKIN, 1985; CHENTSOVA, 1974);
- The outline contour bisectrix (MAKAROVA, 1987);
- Line going through the center of the back part and a central point of the second toe (FARNIEVA et al, 1982);
- Line dependent on a particular foot morphology (DEFINING LAWS OF LADIES FEET SHAPING WITH ELABORATION OF METHODS THEIR MATHEMATICAL DESCRIPTION, 1987);
- Line going through the large toe centre and the centre of the back part (KLUCHNIKOVA, KOCHETKOVA and KALITA, 1985);
- Line going through the centre of the back part and the centre of the fifth toe (THE ANATOMY OF A RUNNING SHOE, 1993).

The contour of the last bottom places between the print and the outline lines of the foot and depending on a footwear type comes nearer to the line of the dimension or the print.

Thus the length of the bottom should take into account lengthening the foot in dynamics and at uprising on a heel, in a case of children's foot – a half-year growth.

Calculated techniques of the bottom designing deduce various ratios between:

1. The foot ball joint girth and all width parameters of the bottom (***American system***) (TECHNOLOGY OF SHOE PRODUCTION, 1933);

2. The bottom length and length parameters, instep girth and width parameters (***Liezhar system***) (TECHNOLOGY OF SHOE PRODUCTION, 1933);

3. Parallelogram sides separating two outside foot toes and other foot parameters (***Crepidam system***) (TECHNOLOGY OF SHOE PRODUCTION, 1933);

4. All foot and last parameters on the basis of the theory of "golden section" that is equal to 21:34 for the case of the last bottom (***A.Hesselbart system***) (TECHNOLOGY OF SHOE PRODUCTION, 1933);

5. Appropriate volumetric parameters of the foot and width parameters of the last bottom (***Maer system***) (TECHNOLOGY OF SHOE PRODUCTION, 1933);

6. All width parameters of the bottom and width parameters of the bottom in the back part and in the ball joint (KALITA, 1988; MAKAROVA, 1987; CHENTSOVA, 1971; CHENTSOVA, 1974; FOOTWEAR LASTS. RUSSIAN STATE STANDARD No 3927-88, 1990; ZIBIN, 1949);

7. length parameters of the last bottom and the total length of a footwear bottom, width parameters and in the ball joint girth (***Circuit G***) (HOLEVA et al, 1981);

8. length parameters of the last bottom and the foot length, width parameters and the ball joint width calculated as 36% of the girth (***Circuit K***) (HOLEVA et al, 1981);

9. length parameters and the foot length, width parameters and the foot width in the ball joint (***Circuit IPS-72***) (HOLEVA et al, 1981);

10. The last bottom width and the foot print width (POLOVNIKOV and FARNIEVA, 1987).

A way of designing the last bottom ***AKA-64*** (HOLEVA et al, 1981; LASTS, 1990; QUALITY IN LASTS PRODUCTION, 1994) found wide application in Europe. It is a combination of graphic constructing the bottom basing on the footprint and calculation of the bottom parameters basing on the width of the ball joint.

The longitudinal-axial vertical section (a profile) of the foot last sets the high-altitude parameters of the shoe. The front projection of the last is not completely identical to longitudinal-axial section as the last front cone profile is directed to the side of the large toe of the foot and has a character of slight turning inwards. Therefore designing the high-altitude parameters of the last is more correctly to conduct basing on the front projection raised on a necessary heel height as describing the high-altitude sizes of the foot in the most complete manner.

According to the techniques (CHENTSOVA, 1971; FUKIN, 1985; ZIBIN, 1982) designing of a profile consists in raising the forepart department of the foot onto the toe spring height, taking into account the total toe allowance to the bottom length and the height of the first toe nail, raising a line of the front cone profile of the last higher than the same line of the foot depending on a footwear design.

Calculation methods of designing the longitudinal-axial section of the last are based on use of analytical ratio of the following parameters: high-altitude and length parameters of the profile to the standard length of the last of the given size (PATRICK, 1962; CHESKI, 1987), the foot length and the length parameters, the ball joint girth and width parameters (STEPANOV, 1960).

There are techniques (MAKAROVA, 1987) combining methods of analytical account of length parameters of the foot with use of the longitudinal-vertical section of the plaster cast. The complex volumetric form of the last is designed based on transverse-vertical cross-sections the situation of which corresponds to the most responsible sites of the foot. In relation to them the whole body of the last is built.

Design of the cross-sections contours is conducted on sections of the plaster cast of the foot, however, their forming is so far ambiguous, that introduces an element of a subjectivism into a process of designing the last sections.

A calculation method of transformationg the main transverse form-sizes of the feet into appropriate parameters of the shoe last was developed on the Faculty of Leather Goods Technology (Moscow Academy of Light Industry). The ratio of two types lies in its basis: determining the form and sizes of transverse-vertical sections (MEDZERYAN and PAVLIN, 1974). In the ratio a reduction of the foot perimeter at its compression by footwear, shrinkage after its removal from the last, expansion of the footwear top because of a force interaction of the foot and the footwear, is taken into account. Similar researches (SUMAROKOVA, 1992; YAKOVLEVA, 1989) were also conducted at Leather and Shoe Department of Leningrad State Institute of Textile and Light Industries (later - Saint-Petersburg State University of Technology and Design).

At designing the cross-sections force interaction of the foot with the footwear is taken into account. In dynamic conditions the heaviest growth of pressure is observed on a lateral surface of the foot, in the back part and on a plantar surface in the basic zones (ZHULIDOVA and FOMINA, 1990 – No 1; ZHULIDOVA and FOMINA, 1990 – No 2) Calculation methods (KOMISSAROV et al, 1994; KOCHETKOVA et al, 1991) of transforming the foot form and sizes into the shoe last parameters on the basis of the force interaction of the foot with the footwear are also applied, based on account of a specific pressure, definition of a relative deformation of the foot by the footwear and its comparison with allowable size of deformation.

Researches of influence of the footwear pressure on a blood system of the foot conducted by Farnieva (FARNIEVA, ILCHENKO and UKHIMENKO, 1968) have established that changing the foot parameters but also the degree of allowable pressure depended on the wearer age and physiological features of the feet of separate groups. The coefficients expressing a ratio of the foot and the last girths depend on changing the foot girths during walking, in the case of children's footwear – increasing the foot at a half-year in connection with growth, and allowable foot compression.

For the analysis of the last form between the forming skeleton contours it is required to allocate the sites of the last having identical laws of shaping.

According to (CHENTSOVA, 1971) such base sites are as follows:

- The center of the last seat (section ***0,16-0,18L***) on a place where oscalcis and the widest place of the rearfoot are;

- The middle of ball joint (cross-section ***0,68L***), occupying intermediate position between outer and inner ball joints (in the foot this site corresponds to the position of the metatarsus-phalangeal joint and is nearly the widest part of the foot, in footwear it brings large loads and pressure points, especially when walking);

- The place of transition from a frontcone profile to a toe profile (section *0,73L*) that meets the origin of the toes department and to a place where the foot bends when moving.

In the work (ZAMARASHKIN and ZAMARASHKIN) the transverse-vertical sections of the last are submitted in polar co-ordinates that permits to allocate four characteristic areas of forming the last sections. These are the back part (till the end of a cone top plane), waist part (up to the vamp point), ball joint part (up to a place where the toe profile begins) and the toe part. The law similar with shaping boundary section carries out design of all sections inside each particular area.

The sections in the back part of the last much differ from the foot form. The cone top plane the parameters of which are defined by the technological features of the footwear manufacturing process forms the top of the sections. As the rearfoot determines the footwear fit the overall dimensions of the last should correspond to the foot outline dimensions in the back part (FUKIN, 1980).

The shank area of the last also differs strongly from the foot form that is partially stipulated by changing the foot shape at functioning in footwear and partially by aspiration of designers to give more aesthetic image to this part of the last.

The ball part of the last is designed in view of that in this area the footwear fixes on the foot. Many techniques define a ratio of the last in ball girth and the foot metatarsus-phalangeal girth. To safe the necessary perimeter in ball joint when the dimension of the sections decreases the top contour of the last section is designed higher than the same contour of the foot.

At designing the toe part sections it is necessary to provide a free arrangement of the toes in the footwear and correct situation of the large toe as it pushes the ground at walking.

5.1.2 Use of unified last surface units

As was spoken above the techniques of the last designing operate with a set of flat patterns intended for the control of manufacturing new styles of lasts. Based on limited number of flat contours it is difficult to define a character of the surface. Therefore very frequently the shoe last designing based on a sample last assumes use of unified parts of the surface for creation of a new style. For example, in practice a shoe factory frequently has a park of standard last back parts that are well tested at technological processs and guarantee a comfort to a wearer.

Designing the last of unified form excludes free construction of the last body and the necessity to develop the drawings and control patterns in each separate case. A classification (CHENTSOVA, 1962) of lasts on age-gender groups in view of a footwear type and the heel height lies in the basis of form unification.

The unification of the shape of the back part and the longitudinal-axial profile up to the ball joint for the adjacent numbers of different groups provides the most rational use of moulded details and unification of appropriate tooling.

The unification of the bottom and the back part shape of the lasts of one group but with different heel height has large technological advantages as supplies with standardized unified parts and tooling.

The majority of western companies develops standards of last designing for particular conditions of their own manufacture (LASTS, 1990). Usually, the back part up to the ball joint is subjected for standardisation, as the back department is the least subjected to changes of fashion trends. There are techniques grouping the shank curves and the back part contours of the last bottom for the neighbour three-four heel heights using one form of the back part of the last for footwear with any heel elevation, one heel size for three - four adjacent sizes of the footwear (chapter 3).

Application of computer engineering permits to use manipulating global sites of the last surface for creation of new styles with the standard elements of the form, to accumulate the libraries of unified last parts, moulded details and units, surfaces of the tooling.

A principle described in a technique of designing the lasts for ladies footwear with various heel heights is rather convenient for use in a system of computer design.

Chentsova and Stulov developed a unification method (CHENTSOVA and STULOV, 1971) of a longitudinal-axial profile and its graphic construction. Linear dependence of a dip value in the ball joint part of a longitudinal profile and the heel height was established.

The last bottom according to Russian Standard for lasts (FOOTWEAR LASTS. RUSSIAN STATE STANDARD No 3927-88, 1990) is narrowed at increasing the heel height that entails a reduction or increase of the last cross-sections dimensions. There are techniques of designing the control patterns for manufacturing lasts for injection moulding (MALETS et al, 1975) ironing and finishing lasts (STEPANOV, 1960) on the basis of a production last. The main disadvantage of these ways of modification the origin shape is use of flat patterns on which it is difficult to evaluate a character of a smooth surface. From this point of view hand-operated methods of fitting a sample last surface to individual foot are more suitable for use in a system of computer last designing.

At manufacturing individual footwear the convenience largely depends on exact conformity of the last to the measurements and shape of customer feet. It is reached by selection a last and its fitting to the measurements (ROZENBERG and ILCHENKO, 1979; LEVIGUROVITCH, PALITSKIY and PODLESOV, 1966).

For correct fitting the last they measure the foot length and ball girth basing on which to choose the most suitable last. At absence of the last with necessary parameters the last with the closest measurements is subjected to processing: they cut a surpluses material and increase a material in places where it is necessary.

Similar operations are made at designing orthopaedic footwear (METHODICAL RECOMMENDATIONS OF PURPOSE AND PRODUCTION FEATURES OF IMPROVED ORTHOPAEDIC FOOTWEAR WITH ORIENTED POSITION OF PLASTER LAST AT VARUS FOOT DEFORMATION, 1976; INSTRUCTIVE MATERIAL FOR ORTHOPAEDIC FOOTWEAR PRODUCTION, 1975; ORTHOPAEDIC FOOTWEAR AT INBORN FLAT-VALGUS DEFORMATION OF CHILDREN'S FEET, 1982; IMPROVED SHOE FOR SHORT STUMP OF A FOOT. USER MANUAL, 1982; INSTRUCTION FOR X-RAY ESTIMATION OF QUALITY

OF ORTHOPAEDIC FOOTWEAR AND PROSTHETIC APPLIANCIES AT PLATYPODIA OF CHILDREN AND ADULTS, 1976).

The lasts, on which footwear for feet with static deformations is produced, undergo the heaviest change (METHODICAL RECOMMENDATIONS OF SIZE-FIT RANGE OF LASTS PARK FOR 1000 PAIRS OF ORTHOPAEDIC FOOTWEAR, 1977). The fit (additional material in ball joint) and waist girth is basically increased, the back part is circulared, less often there are additional material under the metatarsal heads. At designing the last for manufacturing less complex orthopaedic footwear for humped feet the bottom material from the forward department of the calcaneum up to the metatarsal heads is removed out (METHODICAL RECOMMENDATIONS OF X-RAY ESTIMATION OF ORTHOPAEDIC FOOTWEAR QUALITY AT PLATYPODIA, HOLLOW FOOT AND AMPUTATION DEFECTS OF CHILDREN'S FEET, 1978; INSRUCTION FOR MAKING AND CONSTRUCTING PROSTHETIC APPLIANCES, 1974; METHODICAL RECOMMENDATIONS OF DIAGNOSTICS OF PLATYPODIA, PURPOSE AND PRODUCTION OF ORTHOPAEDIC SOCKS FOR ADULTS, 1972; INSTRUCTION FOR PURPOSE AND PRODUCTION OF ORTHOPAEDIC FOOTWEAR AT FOOT AMPUTATION OF MORE THAN 4 CM, 1971).

The unification of separate last sites facilitates a problem of modification of the last shape by a combination of its various parts at hand-operated manufacturing as well as at computer modelling a new form.

However, for development of a uniform system of footwear and tooling designing it is necessary to adapt the rules of designing and manipulating the volumetric last shape for computer designing.

5.2 Methodology of individual last designing

In order to develop a method of last designing on the basis of anthropometric data existing techniques of the last modelling were investigated and rational principles of designing were chosen. Then the experiment of last designing was conducted, consisting in measuring the foot by the device for non-contact photographic measuring the foot parameters and in designing a set of standard contours of the last for ladies court shoes with the heel height 40 mm on the basis of data obtained.

During the experiment it was necessary to reveal the advantages and disadvantages of existing techniques of a shoe last designing and to offer new methods of modelling with the purpose of developing a uniform methodology.

Despite the suitability of separate approaches to the last designing all of them use average foot data. In case of designing individual footwear the parameters of particular foot are just taken into account at fitting the most suitable ready last to the foot.

Thus, the researches conducted on integration and application of existing designing methods to the individual data with the purpose of creation a quite new last and the development of the recommendations of the methods improving proves the knowledge contribution of conducted experiment.

5.2.1 Foot-sizing device and measuring a foot

For realization of the experiment it was created a non-contact device for photographic measuring the foot enabling to receive necessary measurements of a lateral surface of the foot at minimal costs and convenience of processing the results.

The device realizes a way of measuring the toe-ball joint part of the foot by means of one photo camera with illuminating by flat beams (NON-CONTACT DEVICE FOR PHOTOGRAPHIC MEASURING A FOOT, 1992). The image is a direct projection of a contour of the foot dimension from above with designated height isometric lines, formed by light sections. In this case co-ordinate calculations are reduced only to the scale transformations, that admits hand-operated processing of results with use of photo equipment, supplied with co-ordinate grid on an image frame. The method permits to define the foot 3D co-ordinates directly from the photo.

The device, realizing the way, includes a basic platform **1**, supplied with heel rest by **2** for location the foot **3** and illuminator **4**, located on the distance H_0 from the basic platform 1 and on the distance L_0 from the heel rest **2**. The foot **3** is highlighted by flat beams, dispersing from the illuminator 4, directed under the corner α (that is within the limits of 10-65) to the basic plane, and by diffused light (Fig. 5.1). On the basic

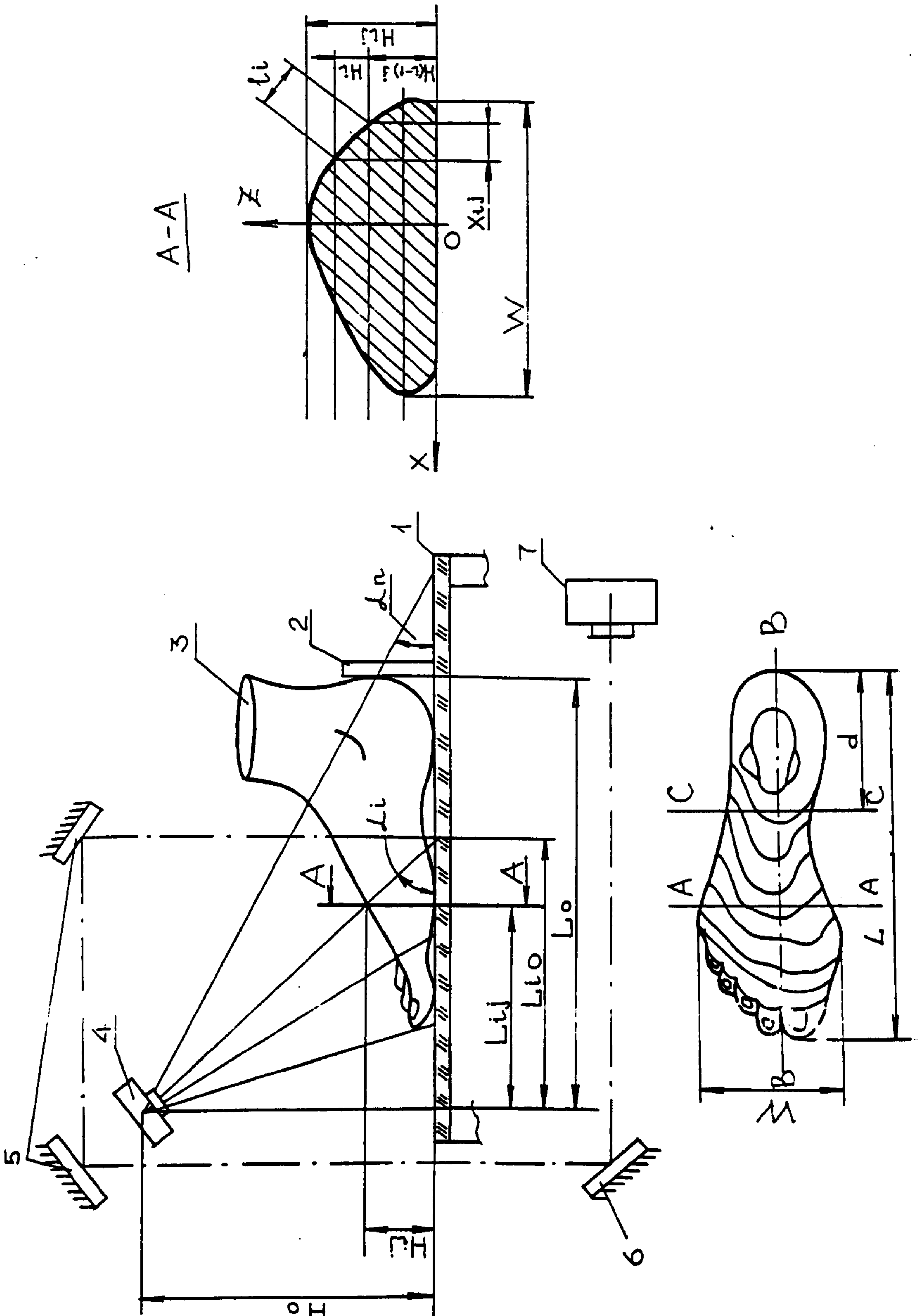


Fig. 5.1 Measurement scheme of the device for measuring a lateral foot surface

platform 1 a plane of symmetry ***B-B***, on which to place the foot **3** and the co-ordinate grid are drawn.

Depending on conditions of filming the device can be supplied by a source of diffused light for additional illumination of the foot. The system of mirrors **5, 6** directs the optical axis of the camera 7, located under the basic platform, perpendicular to the latter onto the toe-ball joint part of the foot **3**. The camera **7** is supplied with remote start-up of the shutter. The system of stationary mirrors **5, 6** serves for reduction of dimensions of the device when using lens with narrow visual angle.

Measurement of the foot is made as follows. The foot **3** is placed on the basic platform **1** and the back part is fixed with the help of the heel rest **2**. The camera 7 exposes image. The distance from the trace of each beam on the basic plane up to the projection of the source to the basic plane is defined from the photo. The operator makes measurements on the photo, on which there is the image of the foot, limited by a line ***B-B***, which is on known distance ***d*** from the edge of the back part. Using the co-ordinate grid, ruler and mask image, the operator defines the overall dimensions of the foot by borders of its images on the basic plane, in view of known situation of the back part (length ***L***, width ***W***), finds the situation of cross-sections of the foot to be measured according to previously measured overall dimensions (***0,5L; 0,68L*** et al), defines the situation of intersection points of these sections with the image of the trace of each inclined beam, projected distance between these points of two adjacent beams ***X*** and distance from a cross-section up to the projection of the source to the basic plane, with further definition of the form and perimeters of the section in view of height of points of each horizontal section from the basic plane, number of the beam and number of the section. All measurements are executed at equal load on the both feet.

Measurements of the linear parameters are made in a rectangular system of co-ordinates that is appropriate to the system of constructing lasts and footwear with the origin of co-ordinates on the conditional foot axis.

Fig. 5.2 illustrates the circuit, identical to the image of dimensional lines and traces of secant light planes on the foot surfaces. Increase of the photo at processing makes $K_l=1,00$. Therefore the image is obtained in full-scale; accordingly all linear parameters to be measured also have natural size, that simplifies accounting.

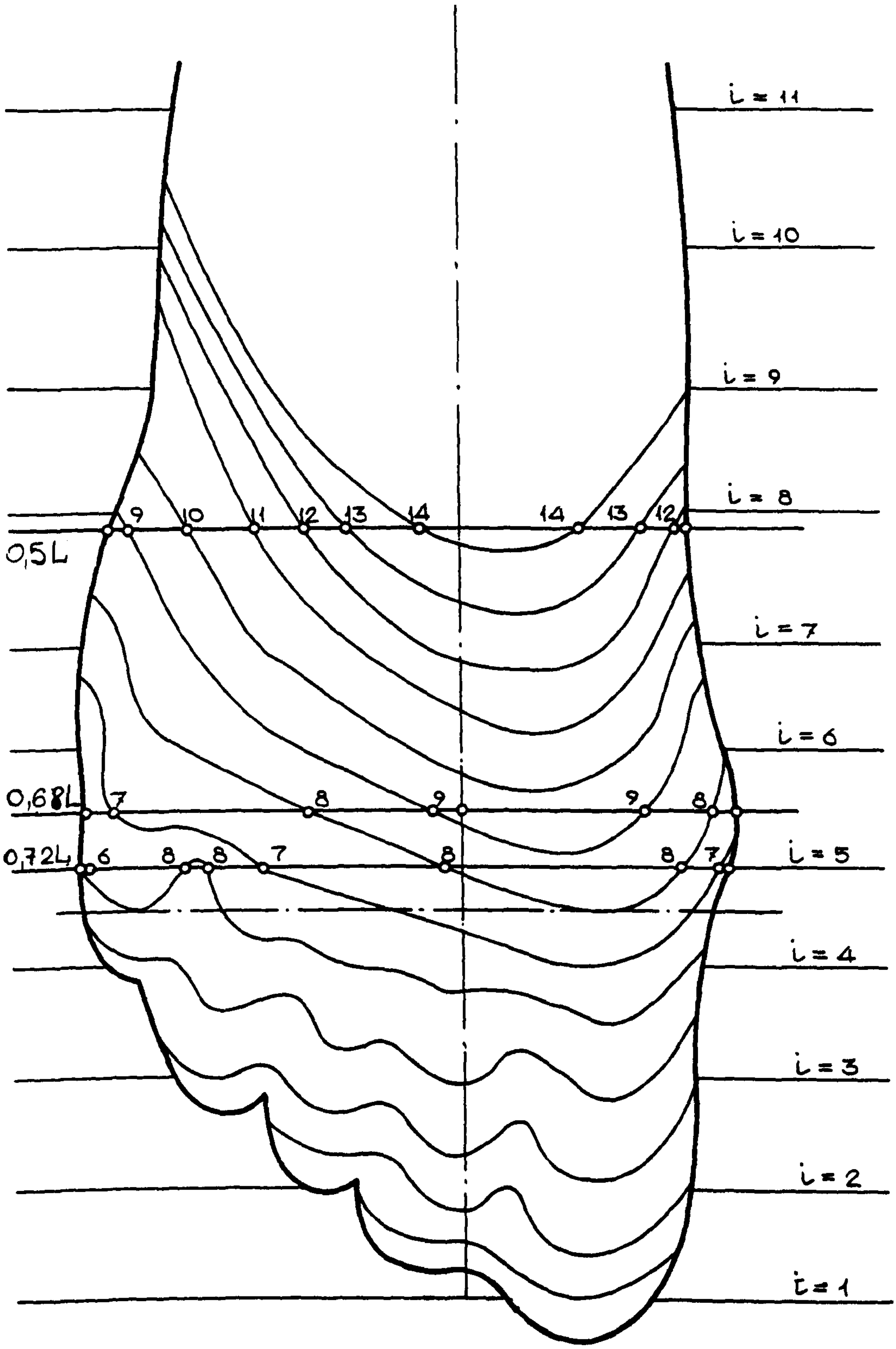


Fig. 5.2 Representation of beams traces on the basic plane and on the foot surface

To get a perimeter of the section it is necessary to draw a line on the photo, the situation of which is defined by anthropometric point or by appropriate account, for example, ***0,68L***. Received lines cross the traces of light beams in points, the situation of which is defined by sliding callipers or ruler.

For each separate cross-section, for example, for the section ***0,68L***, the distance from it up to the projection of the source is defined under the formulae:

$$L_{ij} = L_0 - 0,68L \tag{5.1}$$

where L_{ij} - distance from section j up to the projection of the source to the basic plane;

i - number of a beam ($i = 1,n$);

n – quantity of inclined secant beams;

j - number of a section ($j = 1,k$);

k - quantity of cross-sections;

L_0 - distance from the projection of the source up to the heel rest;

L- foot length.

The section to be measured is built on points with use of values of projection co-ordinates X_{ij}, obtained from the photo, and values of heights of the section points, calculated by the formulae:

$$H_{ij} = H_0 (1 - L_{ij}/L_{i0}) \tag{5.2}$$

where H_{ij} - height of a horizontal foot section situation;

H_0 - height of the source above the basic plane;

L_{i0} - distance from the trace of a beam on the basic plane up to the projection of the source onto the latter.

On the basis of the way described above, the experimental device was developed, the circuit of which is illustrated by the Fig. 5.3. Measurement was conducted by projecting

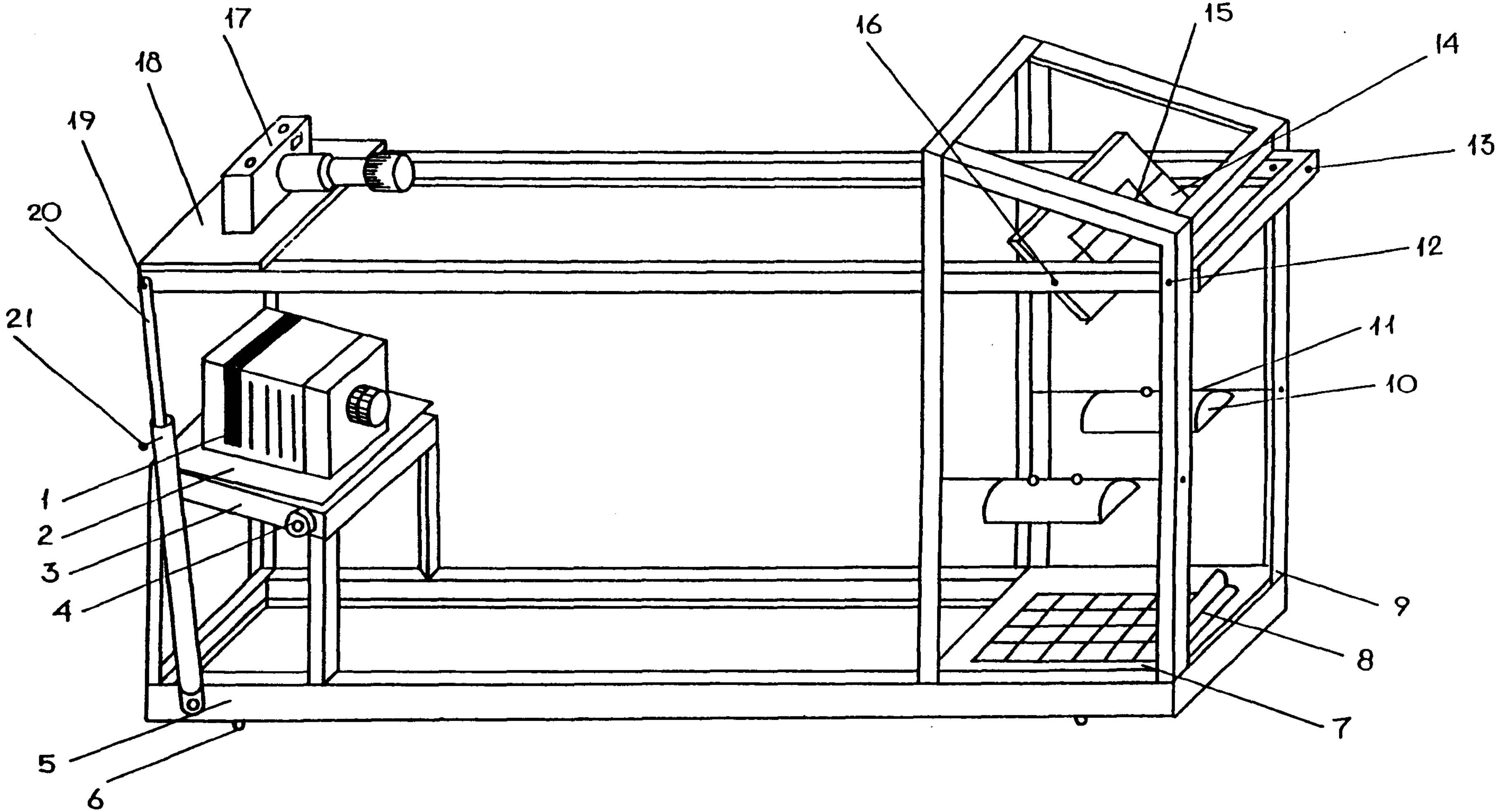


Fig. 5.3 The scheme of experimental device

a bunch of inclined beams from a slide projector ***1***, installed on rotary table ***2***, which was fixed on the support ***3***, onto the foot surface. The support is equipped with a cam shaft (is not shown on the circuit) with a pawl ***4*** for regulation of an angle of the slide

projector optical axis inclination. The support for the slide projector is fixed on a frame-basis **5** with legs **6**. On the other hand of the frames-basis on the basic platform **7**, equipped with the co-ordinate grid and heel rest **8**, the rack **9** is fixed, in the middle part of which illuminators **10** on the pins **11** are installed from two parties above the basic platform.

On the top of the rack on the pin **12** a console **13**, made in a kind of a frame, is fixed, on which a mirror **14** in its turn is fixed, the inclination angle of the latter is controlled with the help of an arm **15** and axis **16**. The mirror serves for reflection of the image of the foot, which is placed on the basic platform, and of horizontal light sections of its surface onto the camera lens **17**. The camera is installed on a platform **18**, fixed on the other end of the console, which is supported by two telescopic supports **20**. The supports, fixed on the pins **19** - by one end - to the frame-basis and by other - to the console, serve for regulation of the situation of the camera. The fixing of the console situation is carried out by means of screws-holders **21**.

Main optical axis of the camera lens should coincide with the centre of toe-ball part of the foot, i.e. the image, falling onto the mirror as well as reflected onto the lens, should include the foot site from ***0,40L*** up to ***1,00L***. When getting the foot image on photographic paper owing to its non-uniformity the deformations occur, influencing an error of measurement. The errors can also arise owing to waiping the image off. In order to get rid of influence of these factors to the error of measurement and to increase its accuracy the foot image was got with the help of enlarger on squared paper in the scale 1:1. The result is illustrated at Fig. 5.4.

The quantity of light beams can be great and therefore their projection onto the basic plane can not be placed within the photo, therefore, as an angle between the light beams has constant value, it was made a simple account of the situation of the light beams projections onto the basic plane. The results of account are indicated in the table 5.1.

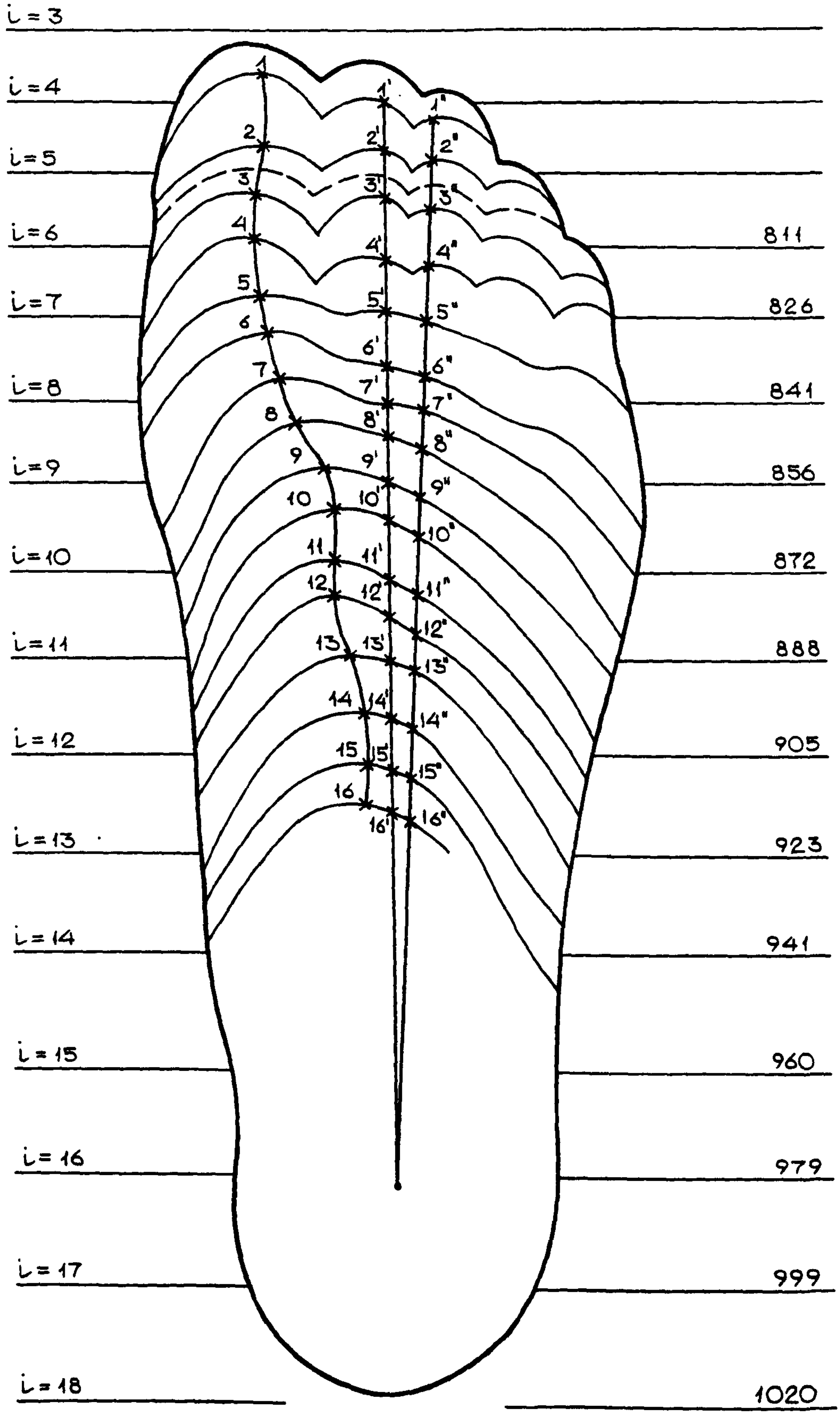


Fig. 5.4 The lateral foot surface image obtained at measurement

To get necessary data for construction of the foot sections the density of light beams can be insufficient, therefore for reception of the section ***0,9L*** additional beam *7'*, locating between the beams *7* and *8* (Fig. 5.4) was conducted.

The data for account of the foot sections, necessary for realization of the researches, are submitted in the tables 5.1-5.8.

Number of a beam, *i*	Angle between the basic plane and a beam, °	Tg α	Distance from trace of a beam on the basic plane up to the source projection onto it, L_{i0}, ***mm***
1	29°38'		
2	29°13'		
3	28°38'		
4	28°13'		
5	27°48'		
6	27°23'	0,5180	811
7	26°58'	0,5088	826
8	26°33'	0,4997	841
9	26°08'	0,4906	856
10	25°43'	0,4817	872
11	25°18'	0,4728	888
12	24°53'	0,4639	905
13	24°28'	0,4550	923
14	24°03'	0,4463	941
15	23°38'	0,4376	960
16	23°13'	0,4289	979
17	22°48'	0,4203	999
18	22°23'	0,4118	1020
19	21°58'	0,4033	1041
20	21°33'	0,3949	1063
21	21°08'	0,3866	1086

Table 5.1 Initial data for account of the high-altitude characteristics

of the foot lateral surface

Number of a beam, *i*	Number of a point, *j*	Distance from point *j* up to the source projection to the basic plane, L_{ij}, ***mm***	Height of the foot point situation, H_{ij}, ***mm***
1	2	3	4
6	1	780	16.1
7	2	793	16.8
8	3	802	19.5

1	2	3	4
9	4	811	22.1
10	5	823	23.6
11	6	831	26.9
12	7	844	28.3
13	8	846	35.0
14	9	853	39.3
15	10	861	43.3
16	11	870	46.8
17	12	877	51.3
18	13	888	54.4
19	14	898	57.7
20	15	908	61.2
21	16	915	66.1

Table 5.2 Data for constructing the foot front cone profile

Number of a beam, *i*	Number of a point, *j*	Distance from point *j* up to the source projection to the basic plane, L_{ij}, *mm*	Height of the foot point situation, H_{ij}, *mm*
6	1'	786	12.9
7	2'	795	15.8
8	3'	803	19.0
9	4'	813	21.1
10	5'	826	22.2
11	6'	835	25.1
12	7'	842	29.2
13	8'	849	33.7
14	9'	857	37.5
15	10'	864	42.0
16	11'	873	45.5
17	12'	882	49.2
18	13'	889	53.9
19	14'	899	57.3
20	15'	909	60.9
21	16'	916	65.8

Table 5.3 Data for constructing the foot profile

Number of a beam, *i*	Number of a point, *j*	Distance from point *j* up to the source projection to the basic plane, L_{ij}, *mm*	Height of the foot point situation, H_{ij}, *mm*
1	2	3	4
6	1'	789	11.4
7	2'	796	15.25
8	3'	806	17.48
9	4'	815	20.1

1	2	3	4
10	5'	828	21.2
11	6'	837	24.1
12	7'	844	28.3
13	8'	852	32.3
14	9'	859	36.6
15	10'	866	41.1
16	11'	876	44.2
17	12'	884	48.4
18	13'	891	53.1
19	14'	901	56.5
20	15'	910	605
21	16'	917	65,4

Table 5.4 Data for constructing the foot transversal-axial section, passing through the foot axis of symmetry

Number of a beam, *i*	Number of a point, *j*	Distance from point *j* up to the source projection to the basic plane, L_{ij}, *mm*	Height of the foot point situation, H_{ij}, *mm*
7		800	13.2
7'		800	18.4
7'		800	18.4
7'		800	18.4
7'		800	18.4
7		800	13.2
7		800	13.2

Table 5.5 Data for constructing the foot cross-section *0,90L*

Number of a beam, *i*	Number of a point, *j*	Distance from point *j* up to the source projection to the basic plane, L_{ij}, *mm*	Height of the foot point situation, H_{ij}, *mm*
11		844	20.8
12		844	28.3
12'		844	35.9
12'		844	35.9
12		844	28.3
11		844	20.8
10		844	13.5

Table 5.6 Data for constructing the foot cross-section *0,73L*

Number of a beam, i	Number of a point, j	Distance from point j up to the source projection to the basic plane, L_{ij}, *mm*	Height of the foot point situation, H_{ij}, *mm*
12		855	23.2
13		855	30.9
14		855	38.4
14		855	38.4
13		855	30.9
12		855	23.2
11		855	15.6

Table 5.7 Data for constructing the foot cross-section *0,68L*

Number of a beam, i	Number of a point, j	Distance from point j up to the source projection to the basic plane, L_{ij}, *mm*	Height of the foot point situation, H_{ij}, *mm*
12		852	24.6
13		853	31.9
14		854	38.8
14		855	38.4
13		857	30.0
12		858	21.8
11		859	13.7

Table 5.8 Data for constructing the foot cross-section *0,68/0,72L*

The results of the sections designed are submitted in the Appendix A.

When developing a way of transition from a foot to a last, it is necessary to proceed not only from 3D foot measurement data, but also from plantogram of the foot in view of changes of the form and sizes of the latter in various positions, and from the data of allowable compression of the foot by footwear in separate anatomical sites.

With the purpose to get the information about plantar foot surface its plantogram was received, the processing of which was carried out by the technique (CHENTSOVA, 1974) (Appendix B). Length, width and high-altitude parameters of the both wearer's feet are indicated in the table 5.9.

Measurements	**Distance up to the point to be measured**	**Average foot**	**Right foot**	**Left foot**
1	2	3	4	5
		Length parameters:		
Foot length	1,00L	239	238	240

1	2	3	4	5
5th toe end	0,8L	190	206	205
Internal ball	0,73L	174	173	175
Outside ball	0,62L	145	160	163
Instep point	0,42L	100	94	95
Instep girth	0,55L	131	131	132
Center of internal ankle	0,26L	60	55	55
Center of outside ankle	0,20L	50	46	48
Heel centre point	0,18L	43	43	43
Width measurements:				
Outside ball width	0,62L	89	88	84
Internal ball width	0,73L	89	87	85
Seat width	0,18L	65	53	56
Height measurements:				
Big toe nail	0.9L	24	22	23
Foot middle	0,5L	59	56	56
Instep point		76	80	83
Girth measurements:				
Outside ball	0,62L	227	213	213
Internal ball	0,72L	219	206	207
Short heel girth		310	290	290
Instep girth	0,55L	230	210	210
Above outside ankle		216	200	200
Maximum girth of shank muscle		350	340	340

Table 5.9 Individual foot data (Wearer: lady, 25 years, and height –164 cm, weight – 54 kg)

5.2.2 Defining the base plane of the last

When designing a last the base plane passes through points of the feather edge belonging to the stick axis in the seat (point *O*) and in the toes - to a point of normal toe allowance standardised by Russian Standard for lasts (FOOTWEAR LASTS. RUSSIAN STATE STANDARD No 3927-88, 1990) (point *O''*).

Such base plane does not depend on changing a size of alternative design line (decorative allowance) in toes and permits to execute design of comparable sections of the lasts with various heel elevations (*He*). In parallel with the base plane *I-I* the planes of the basic last sections are situated: a line of feather edge in section *0,18L* (*a-a*), a line of feather edge in section *0,68L* (*b-b*) and a line of cone top plane (*c-c*) (Fig. 5.5).

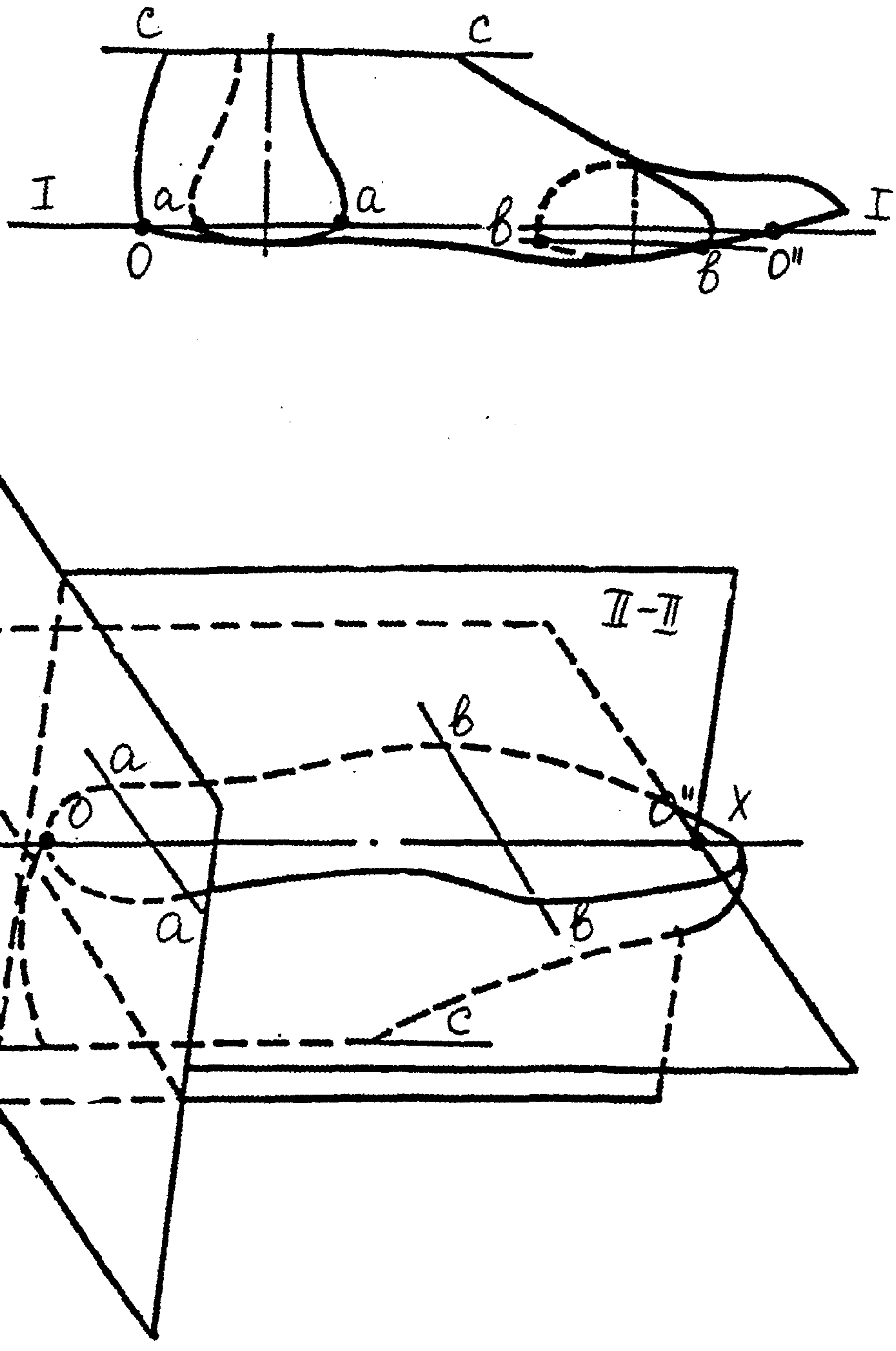


Fig. 5.5 The base plane of the last

Perpendicular to the base plane a vertical-longitudinal plane *II-II* that passes through conditional axis of a bottom pattern designing and a vertical axis *III-III* used for designing cross-sections locate.

5.2.3 Last bottom pattern

The bottom pattern is the basis for the model last design. Form and sizes of the bottom pattern are defined according to a plantogram being formed by the draft and an imprint of the foot in weight-on conditions.

At insole designing several co-ordinate systems are used ensuring correct transition from sizes and form of the plantogram to the bottom pattern, as well as correct reproduction of the insole lines. The plantogram is oriented in rectangular co-ordinates XOY, where OX_a coincides with direction of the foot axis - conditional line passing through a heel centre point and joint centre point (Fig. 5.6). The stick line of the last and the insole OX connects the distantly spaced point of the toes and the heel point. Axes OX and OX_a diverge from so-called "pternion" point (p. O) under a corner $3°$ in a direction to the second and the first toes intervals respectively.

Designing a contour of the insole in a rectangular co-ordinate system is begun with a seat. The initial point of construction is point O, the position of which in the co-ordinate system is determined by quantity of a shift of the last bottom (S) concerning a draft point of a back curve. The quantity of S is defined under the formula:

$$S = 0{,}02L + 0{,}05\ He \qquad (5.1)$$

S = 0,02 * 238 + 0,05 * 40 = 6,76 mm (the shift of the bottom for the last designed with the middle heel height).

According to the formula at increasing the heel height on *10 mm* the shift is increased at *0,5 mm*). It is of special importance at the last shape modifying.

From the point O on the stick axis OX segments determining position of all cross-sections are postponed. Sizes of the segments are expressed as a percentage of the foot length (L) and taking into account (deducting) the shift S. In the case of individual last designing a situation of control anthropometric points is find from a plantogram and through them perpendiculars are dropped to the insole stick axis.

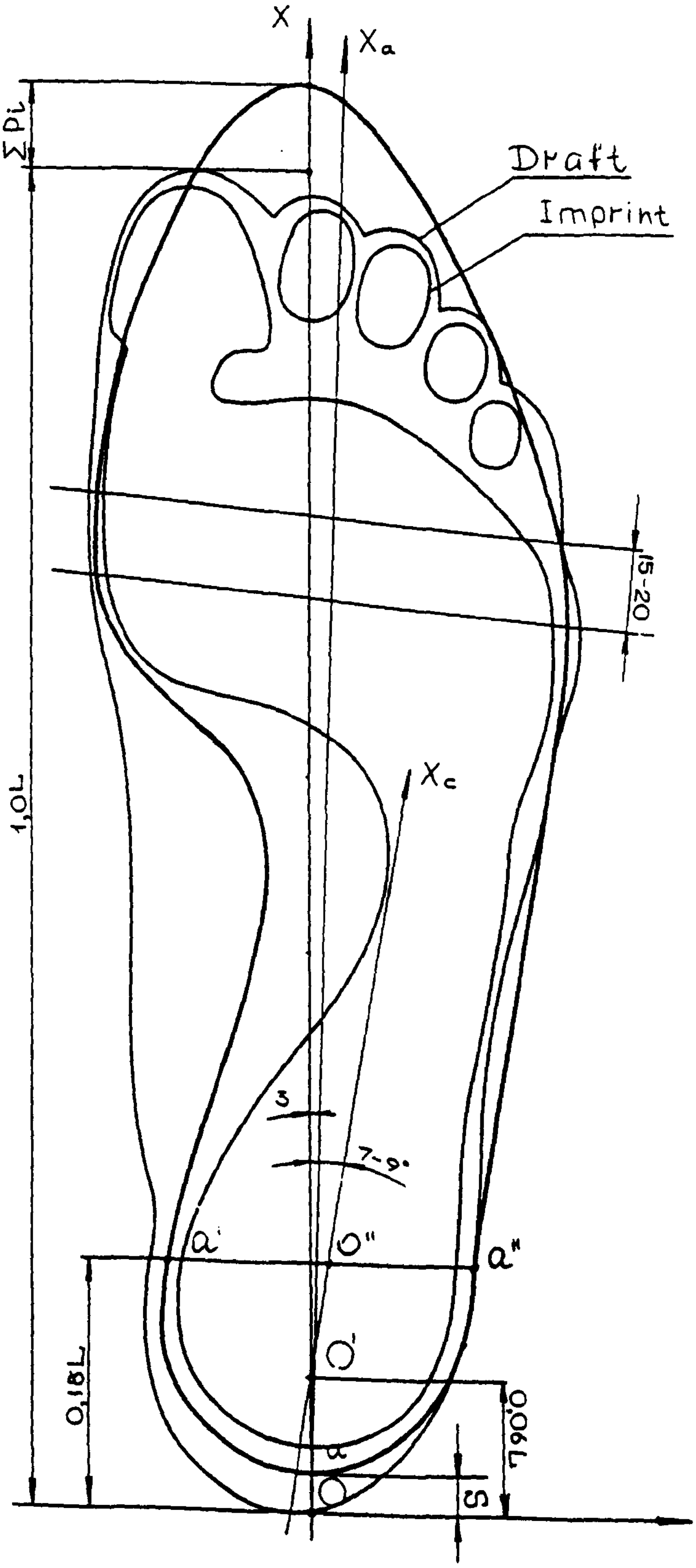


Fig. 5.6 Last bottom pattern

The toe contours are designed pursuant to the sketch of the last form, agreed with a stylist or projected by a designer himself. The main reason for designing the toe part is to create room for the toes, and to allow toes to lie straight.

To the length of the insole in toes it is provided a distance ΣP_i - allowance calculated by taking into account medical recommendations - minimum allowance (*5 mm* - for ladies footwear and *10 mm* - for other and ladies casual footwear) - and fashion trends - decorative allowance (CHENTSOVA, 1974).

Minimum allowance:

for chrome footwear is equal to *0,045 L*;

- for Russian leather bootees - *0,06 L*;
- for chrome boots - *0,055 L*;
- for Russian leather boots - *0,07 L*.

For a designed last bottom a minimum allowance is 5 mm and the total one is equal 15 mm.

According to a technique(CHENTSOVA, 1974) the inner line of the insole toes should be designed differentially in relation to inner tangent ***TT'*** in accordance with age groups in view of deviation corner of the big toe (β). Lasts for children's footwear should have this corner close to zero, for school group - ***6°***, for men's and ladies groups - ***8-10°*** (Fig. 5.6).

It is recommended to narrow the footwear toe part shape only outside of the foot toes on length in view of their functional shift, and shape of the toe part of children's footwear should completely correspond to the form of a normal child's foot. These rules are fair and at individual last designing as enable to take into account an individual corner of the large toe deviation that promotes correct accommodation of the foot toes in footwear. However, in lasts for high-heeled shoes much more narrowing of the toe part of the bottom is possible.

The last seat should have the symmetrical form around the relative heel axis AX_c and the forepart is to be slightly indicated inwards that corresponds to a structure of normal foot and medical-orthopaedic requirements. Such construction of the seat also meets the rules of footwear designing, as the heel contour is designed symmetrical to fit both left and right lasts.

To construct the insole seat of the symmetrical form a position of AX_c axis is determined. For this purpose from the point O upwards on the stick line OX the value of

OA= 0,06L = 0,06*238 = 14,28 cm **(5.2)**

is postponed. Through the point A to the right a line under a corner $7°$ is carried out, which is the axis of symmetry of the last bottom back part. Then the extreme points of intervals of the cross-sections are transferred onto the obtained axis by graphical way (perpendicular to the axis) and, being guided by the specifications of width of the back part, the contour is made out in accordance with the heel axis up to the cross-section *0,28L* (CHENTSOVA, 1971).

If to design individual last for a foot turned outwards or considerably inwards it is possible to use the recommendation (KLUTCHNIKOVA et al, 1985) and to draw an axis of symmetry of the back part in a direction of the third toes interval (Fig. 5.6).

As against this there is an opinion that the back part of the insole should not be symmetrical and its internal part is to be a bit more convex (instead of being parallel to outside contour of a draft) than outside one. However, despite a conformity of such approach to anatomical structure of a foot it is very inconvenient in bulk production as it becomes impossible to use symmetric heels and other tooling.

Outside of symmetric contour of the back part the bottom contour is designed in relation to the bottom stick axis. The lines of the imprint and the draft of the plantogram are boundary conditions for the bottom line, which depending on a footwear type may be closer to either an imprint line (for model ladies footwear on high heels), or to a draft line (for inflexible type of footwear). An average casual footwear bottom pattern takes intermediate position.

Contour of the insole back part is designed a little wider then the foot imprint (between the draft and the imprint) to avoid sharp overhanging the seat part of the footwear over a heel, that it is especially important for ladies footwear on high heels (CHENTSOVA, 1974).

In a waist part the line of outer part of the insole (where the midfoot is) rectifies accordingly to the foot imprint, and within the inner part a smooth curve is carried out, that, to some extent, corresponds to the character of the foot imprint in that site. The degree of the line bending near the ball joint site from the inner part should of maximum come nearer to the foot imprint, as it is intended to hold the foot arch in a footwear. But the sharp bend of the last insole complicates the technological process of moulding the footwear: at lasting folds can be formed in this site of the footwear upper. Therefore, lasts for mechanical manufacturing footwear have a quieter line of the inner part of the insole shank. In lasts for model footwear, especially for a ladies shoe on high heels, the character of the insole line in this site is more approximate to the average foot imprint. That is why, Russian Standard for lasts (FOOTWEAR LASTS. RUSSIAN STATE STANDARD No 3927-88, 1990) rations only outer part width of the insole shank (CHENTSOVA, 1974).

As actually the bottom of footwear is of the space form, it is necessary to define a situation of a featheredge of the last bottom.

The last featheredge, which is a line of crossing its side surface with the bottom, is connected to the technological features of the footwear manufacturing from flat details. In handicraft manufacture the featheredge served as a checked reference, on which a piece of the leather, nailed to the bottom, was cut. And at present, the bottom parts are oriented concerning the last featheredge. In the foot the bottom smoothly transforms into the lateral surface and from the point of view of the footwear comfort the feather edge in the last is superfluous and in all probability will disappear, for example, in a whole-moulded (injected) footwear and one assembled from pre-moulded units.

The position of the featheredge of the last was not given due attention for a long time. The featheredge on all length except of the seat (up to section ***0,28L* - *0,30L*** - where the heel is in footwear) and basic section ***0,68L*** was placed arbitrary from inner and outer sides. The absence of determined position of the feather edge in all lasts hindered designing of the footwear and technological equipment, that related to moulding and attaching the footwear uppers and bottoms, and had an effect on footwear deformities character.

As the analysis of the last construction shows, the position of the featheredge from the inner and outer parts from the section ***0,68L*** and further to toes changes on sections slightly (within the limits of *1,5 mm*). It permits pending reception of the physiological characteristics to design a position of the featheredge from the section ***0,68L*** and further on slides in one plane. Such position of the featheredge of the last is necessary at designing mould-units for injection moulding of the footwear bottoms (CHENTSOVA, 1971).

The internal bottom of a shoe should provide accommodation of all plane of support of the foot not only at static standing but also at functional movements, especially of distal part. So, it is known, that at movement of a person and downturn of the foot arch the displacement of ball joint ahead occurs, and the inner and outer ball joints do not displace on equal dimensions. This condition requires the ball joint part of the insole to be designed corresponding to the average size of the metatarsus-phalangeal joint shift ahead (*15-20 mm*).

Displacing ahead, ball joints accordingly displace the toes of the foot simultaneously. Thus, to avoid deformation of the footwear upper a contour of the inner part of the insole from the section ***0,62L*** (outer part) and ***0,73L*** (inner part) ought to be designed without sharp narrowing in view of the size of the ball joint shift irrespective to the toe form. Similarly the shift of the toes are taken into account (CHENTSOVA, 1974).

Besides, they construct a horizontal projection of the last that up to the ball joint passes on a similar line of the foot, further it goes narrower than the foot line. The size of the outline in toes can narrow in section ***0,8L*** for ***9 %***, and at distance *10 mm* from the most apart point of the foot toes - for ***20 %*** (CHENTSOVA, 1971) (Fig. 5.6).

5.2.4 Last profile design

Profile design is another necessary section for the creation of the last image. The side projection is not equal to the stick line cross-section of the last that used for the new last shape control, but more completely describes an outline of the last. The orientation of foot side projection depends on two conditions: the toes (from 0,68L section) must be located on a horizontal surface, and the back part must be elevated on the heel-height (Fig. 5.7).

As a centre of support in the ball joint they take a projection of a centre of a foot bending in ball area – point ***3'*** (FUKIN, 1985), which meets the middle of the first metatarsal head (Fig. 2.21). This approach is also expedient from the point of view of modifying the last shape at changing the heel height.

The front profile of the last should provide natural rolling the foot in metatarsus-phalangeal joint. Therefore, the forepart in the point of normal allowance (point ***5***) should be upraised at the toe spring (T_s) that depends on the shoe type, foot length and the heel-

height (in a point of normal allowance T_s=***8-15 mm*** according to Russian Standard for lasts (FOOTWEAR LASTS. RUSSIAN STATE STANDARD No 3927-88, 1990).

Ts = 0,067L - 0,1He (KLUTCHNIKOVA et al, 1985) **(5.3).**

Ts = 0,067 * 238 - 0,1 * 40 = 11,95 mm (for the designed last) (Fig. 5.7).

At less toe spring the foot in footwear slips ahead, at greater - on plantar surface of the foot the metatarsal heads are designated and become overloaded. In children's footwear it is expedient to increase the toe spring outside of the ***0,9L*** (CHENTSOVA, 1974). For Russian leather and rigid type of footwear it is recommended to enlarge the toe spring for 1/3 (FUKIN, 1985).

The toes of the last (section ***0,90L***) should be constructed to provide a correct position of the big toe on the axis, and height conditions of normal toes functioning when walking. The big toe bears a very large load: a person repeals by it from a ground plane at movement.

The toe profile till ball joint is designed in view of height of the first toe nail phalanx within the interval ***0,9L-1,0L*** and is defined by Russian Standard for lasts (FOOTWEAR LASTS. RUSSIAN STATE STANDARD No 3927-88, 1990) coefficients ***0,11*** and ***0,09*** of girth in section ***0,68L/0,72 L*** (Ball Girth).

The height of the last toes at the end level of the big toe (H_1) is:

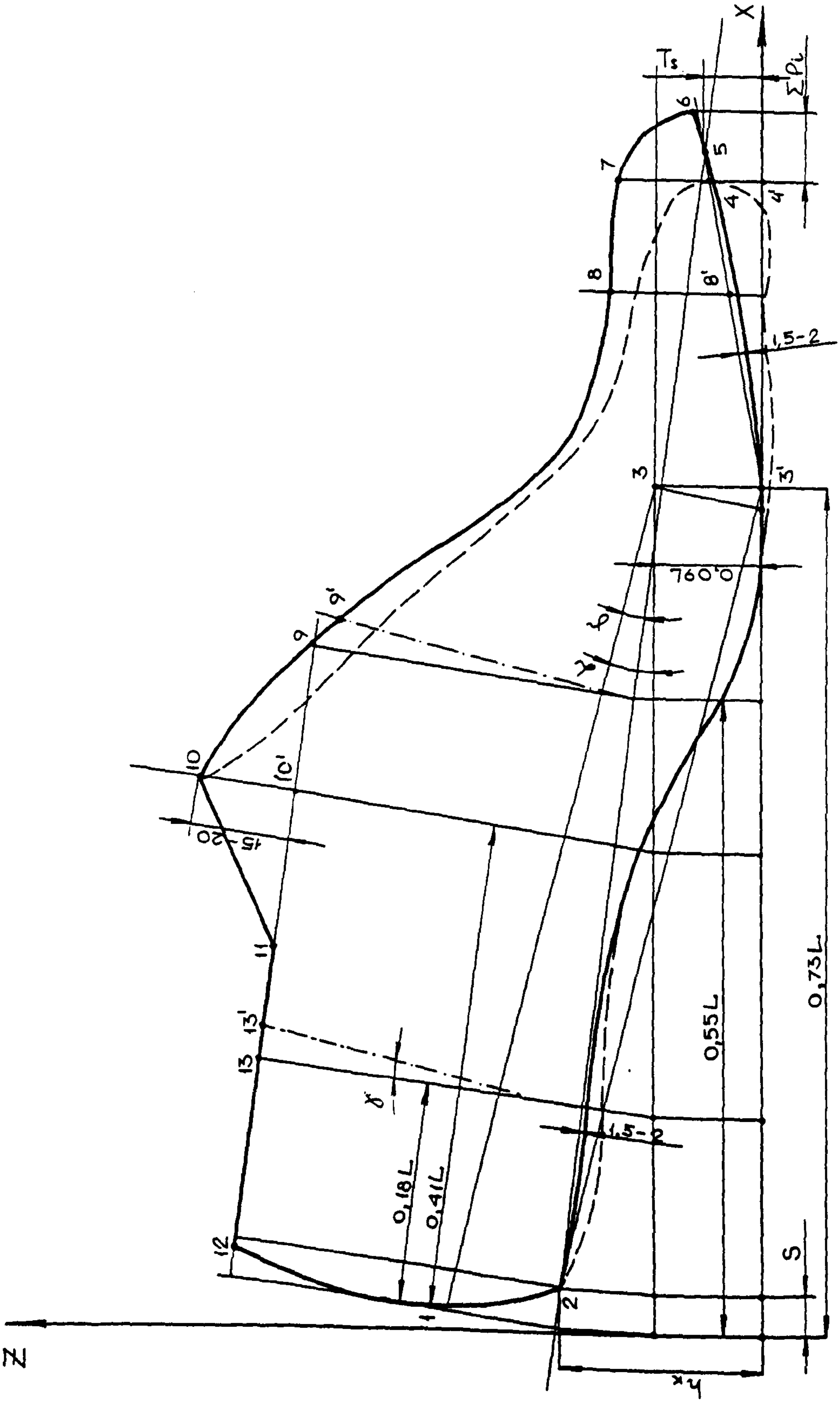


Fig. 5.7 Last profile design

$H_1 = 0{,}085L$ **(5.4)**

- for Russian leather footwear:

$H_1 = 0{,}1L$ (KLUTCHNIKOVA et al, 1985) **(5.5)**

Height of the last designed in the section ***0,9L***:

0,11 * 220 = 24,2 mm (point *8*);

In the section ***1,0L***:

0,09 * 220 = 19,8 mm (point *7*).

Except the height of the toe cross-section a profile contour in the area from the vamp point up to the top point of the front cone profile is affected by a height of the ball joint section accepted to be equal to ***20 %*** of the section ***0,68/0,72L*** perimeter (CHENTSOVA, 1974).

The ball girth of measured foot is **220 mm**; hence the height of the ball joint section will be equal to **44 mm**.

In order to define the heel point on a perpendicular to a support restored from ***a*** point they postpone a heel height (point *2*). Through the point ***2*** and the most convex point of the foot heel curve they draw a contour of a heel curve of the last profile that is a smooth convex curve. To developing the contour the large attention was given in the work (MAKARICHEVA, 1972). On the basis of detailed anthropometric researches of seats of ladies feet a rational configuration of the last heel curve with zero heel elevation ensuring good fitting was offered.

Through the point of heel curve ***1*** and point ***3*** V.A. Fukin (FUKIN, 1985) offers to conduct neutral basis for perpendicular orientation of transverse-vertical sections of the last, identity situations of the same sections is thus saved at various heel elevation. This circumstance was taken into account when choosing an axis of turning the toe or back part of the last at manipulating its form.

However, such orientation of the cross-sections does not correspond to usual one in perpendicular to the bottom axis lying on a base plane. According to (CHENTSOVA, 1974) and as mentioned above, the base plane of the last construction is a plane passing in the basis of the last body through the points of the feather edge (heel point – point ***a***) and in the toe part in the point of normal toe allowance, rationed by Russian Standard for lasts (FOOTWEAR LASTS. RUSSIAN STATE STANDARD No 3927-88, 1990) (point ***5***). Such base plane does not depend on changes of value of a decorative allowance in the toes and permits to design comparable sections of the last with different heel height. In parallel to the base surface planes of the basic last sections are located: feather line of the bottom in sections ***0,18L, 0,68L*** and the cone top surface.

Thus, between the sections drawn perpendicularly to the base plane and independent basis a corner γ is formed. The cone top plane as was marked above is located in a plane that is parallel to the base plane and perpendicular to the planes of the cross-sections.

The form of the bottom essentially influences convenience of the footwear. The internal structure of insole should provide a convenient "cradle" for the foot that is appropriate to a complex relief of a plantar surface. Independently from design features the internal support bottom of the last should reflect the foot bottom relief and in seat part have an extension to create a room for the foot back part (CHENTSOVA, 1974).

In practice the bottom in back part is designed flat or on the contrary with a dip within the limits of 1,5-2 mm, that is determined by a way of moulding an upper on the last. At external way of moulding, firstly, the insole used is made of sheet materials, and secondly, at tack and nail lasting a metal plate on the last bottom is necessary, i.e. the problem occurs to mould sheet materials. Therefore to decide the problem it is offered to form the cradle for the foot for the account of insert details (ready-made insert insoles et al).

At an internal way of moulding (injection moulding) the dip in the back part could be designed up to 15 mm, as well as the feather edge could be absent for the complete conformity of the last bottom to the plantar surface of the foot.

However, much remains to be done that at more conformity of plantar surface of the foot to the bottom pattern of the last, than less footwear ventilation is, i.e. the hygienic properties are considerably worsened.

The contour of a shank part of the last profile practically coincides with a similar contour of the foot. The top contour is defined by a construction of the cone top plane.

5.2.5 Last cone top plane designing

Cone Top Surface (ankle opening surface) is the surface that is the back cone top plane extended to the top of the front cone.

Strictly parallel to the base plane positioning of the cone top surface, as practice shows, has a number of significant advantages in comparison with the plane possessing high instep (point ***10***).

In the beginning of developing a method of the last modelling by drawing the back cone top plane was placed under a corner ***145°*** (point ***10*** on Fig. 5.7) to the top part of front cone profile of the last. Expediency of change of designing back cone top plane was hereinafter determined. High instep of the back cone top plane in lasts basically has not practical significance during assembling and moulding the footwear, but at the same time increases the charge of material for the last manufacturing, that results in increasing price of the last, narrowing a raw base of the last manufacture and increasing the weight of the last.

The known design of flat cone top plane (points 9-11-12 on Fig. 5.7) permits to remove marked defects and considerably simplifies the method of last designing by drawing. However, for manufacturing several footwear types the accepted position does not exclude an opportunity to apply lasts with high cone (CHENTSOVA, 1971).

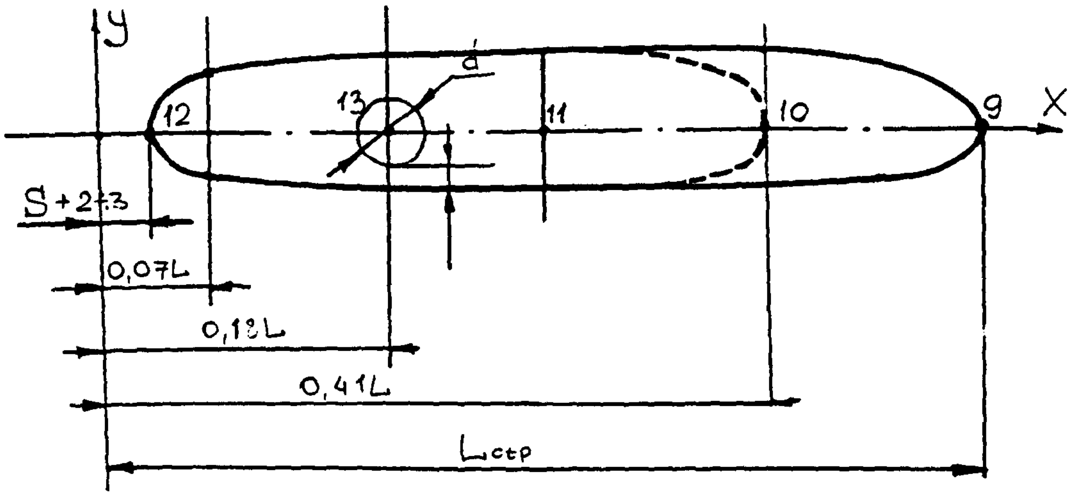
The parameters of the back cone top surface are expressed from the formulae below:

Htp = 0,2 L + 20 = 0,2 * 238 + 20 = 67,7 mm - height;

Ltp = 0,41 L = 0,41* 238 = 97,58 mm - length - instep point (point 10 - checkpoint in the area of foot bend).

The lasts for footwear on high heels have minimum width of the back cone surface (Fig. 5.8). Width of the latter is determined by a diameter of thimble installed in section ***0,18L***, and by thickness of wall (***t=4 mm***) of each part of the section. The total width of the cone top surface of the court shoe last will be **18 mm**, for closed footwear of ladies group - ***22 mm***. In lasts of men's group - ***25 mm*** for closed footwear and ***40 mm*** - for

Fig. 5.8 Last cone top plane design



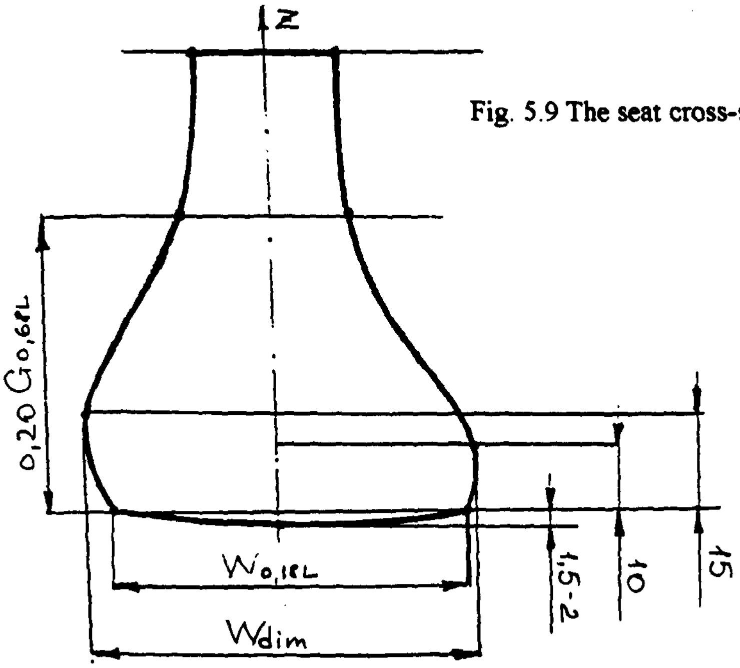


Fig. 5.9 The seat cross-section (0,18L) design

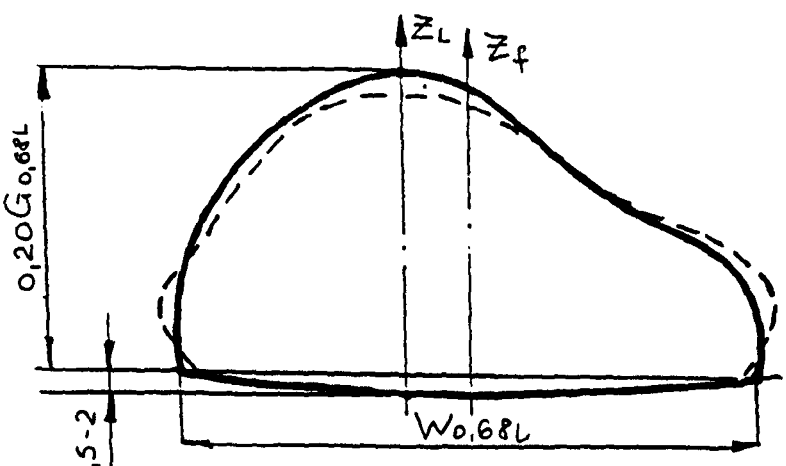


Fig. 5.10 The ball joint cross-section (0,68L) design

Russian leather footwear. The parameters of three sections of the back cone top plane are submitted in the table below (FUKIN, 1985).

Parameters	Groups of lasts					
	Sections	Ladies	Ladies	Ladies	Men's	Men's
Heel height, mm		20	40	60	20	20
Width, mm	*0,07 L*	6/9,6	6/8,5	6/7	6/9,5	14,7/15
Width, mm	*0,18 L*	9/12	8,5/11,5	8/10	9,4/15,6	15,6/21,3
Width, mm	*0,41 L*	7,8/11,7	7,8/11,7	4,8/11,6	11,6/12,6	11,2/15,4

Table 5.10 Parameters of the cone top plane sections

5.2.6 Last girths design

As spoken above, the complex volumetric form of the last is designed basing on transverse-vertical cross-sections the situation of which corresponds to the most responsible sites of the foot. In relation to them the whole body of the last is built.

Despite a plenty of attempts to invent a technique of slides constructing, the techniques of cross-sections design are of particular difficulty and still outstanding problem. So, in the work (CHENTSOVA, 1971) the usual approach to design the transverse-vertical section of the last is stated, which, however, is poorly justified and based on use of well-tested sections. The method consists of application of analytical ratio of width parameters of the sections and a norm of the bottom width in sections ***0,18L*** and ***0,68L*** or the ball girth, high-altitude parameters of the back part sections and standard height of the cone top plane.

This method can be used in case of designing the last for average foot. When it is required to design individual last one should proceed from individual data.

As was mentioned earlier, the ***shank-back part*** of the last considerably differs from the foot form. The ***seat sections*** of the last are built proceeding from the foot not loaded with the weight of the body (the foot in free condition). Such designing in wearing provides good stiffener bearing against the foot without its compression at the expense of increasing the back part measurements at its loading with the weight of the body. The stiffener in footwear thus works at stretching. For best embracing the foot by the footwear the top part of the seat sections is necked. On the bottom, as was said above, a cradle for the seat is provided. The featheredge from both sides is designed in one plane, that provides a direct positioning the foot in the footwear (Fig. 5.9) (CHENTSOVA, 1971).

The contour of the ***back part section*** is determined basically by four pairs of parameters (same parameters for the internal and outside parties): width of the cone top plane (Tabl. 5.10), width of already designed bottom of the last in appropriate sections (in the case of standard last – standardized parameter), dimensional parameters (that are postponed at height of 15 mm from the internal party and 10 mm - from outside) and width in a place of changing a curvature of a lateral surface of the last (Fig. 5.9).

To define the latter it is necessary to find a location of so-called "***waist***" section. The waist protects a foot from flattening in metatarsus-phalangeal joint. It is especially important to provide the waist in lasts for ladies court shoes. As the main purpose of constructing the last sections is further application of a method of computer last modelling (see 7.3) the waist section is chosen in a place of joining the ball joint section the last profile. To provide normal functioning the foot toes at movement the height of sections in a region ***0,68L-0,73L*** is almost equal to ***20 %*** of perimeter of the section ***0,68/0,72L*** (CHENTSOVA, 1971).

For designed last this value is **20 % of 220 mm = 44 mm**. Hence, at the height of 44 mm from the base plane the concave sites of a lateral surface of the back part section become convex (Fig. 5.9). A dip of the section bottom contour is taken equal to 1,5-2 mm.

The basis of the ***ball joint section*** is designed in accordance with the imprint of a loaded foot, and its dimension is determined by the perimeter of a non-loaded foot. The top part of the section in comparison with the foot is located a little higher, that is determined basically by changing the foot form at functioning. The featheredge is designed as well as in the section ***0,18L*** at one level (Fig. 5.10).

Outside contour of the section usually has a concavity that seems to be inexpedient, since at upper lasting it does not adjoin to the last in this place.

It should be noted that sections in the ball joint and in ***0,73L*** are extremely important, since the character of a line of the top surface at the site ***0,73L*** defines how the footwear upper bears against the foot, that is very difficult to adjust in the cross-section by design of footwear upper. Special significance this section has in lasts for ladies court shoe as far as it defines the character of designing the shoe fit line (Fig. 5.11).

The section ***0,73L*** is designed similarly to the section ***0,68L*** but taking into account the placement of rationed from outer part segment in section ***0,80L***, i.e. the bottom contour is designed from the outer part according to the imprint of the 5th toe. To provide normal functioning the foot toes at movement the height of the given section is accepted exactly equal to ***0,2*** of a perimeter of girth in section ***0,72L/0,68L***. The situation of the featheredge is at one level from both sides.

Section ***0,90L*** passes through the imprint of the big toe, therefore its top part pursuant to Russian Standard for lasts (FOOTWEAR LASTS. RUSSIAN STATE STANDARD No 3927-88, 1990) should be ***0,11*** of the girth perimeter in section ***0,72/0,68L***. Designing this section is similar to the section ***0.73L***, but thus taking into account the projected form of the toes of the last and Russian Standard for lasts (FOOTWEAR LASTS. RUSSIAN STATE STANDARD No 3927-88, 1990) specification for a segment of the section from the inner part (Fig. 5.12).

The given section is not the basic, however it corresponds to the metatarsus-phalangeal section of the foot. From the outer part of the last in this site it is designed so-called "waist", which provides protecting the foot from flatting in metatarsus-phalangeal joint. It is especially important to provide the waist in lasts for ladies court shoes.

Fig. 5.13 and 5.14 illustrate the sections ***0,41L*** and ***0,55L*** designing that correspond to the end point of the cone top plane (flat design and with high instep respectively). The shank area of the last strongly differs from the foot form, that is partially stipulated by changes of the foot form at functioning in footwear, and partially - by aspiration of designers to give this part of the last a more aesthetic look.

In the other sites the last cross-sections are designed pursuant to the basic ones taking into account stato-dynamic condition of the foot. In a case of absence of appropriate foot sections it is possible to use unified good-tested patterns of transverse-vertical sections (especially in a back part) as the parameters of measured foot are almost average (Table 5.9).

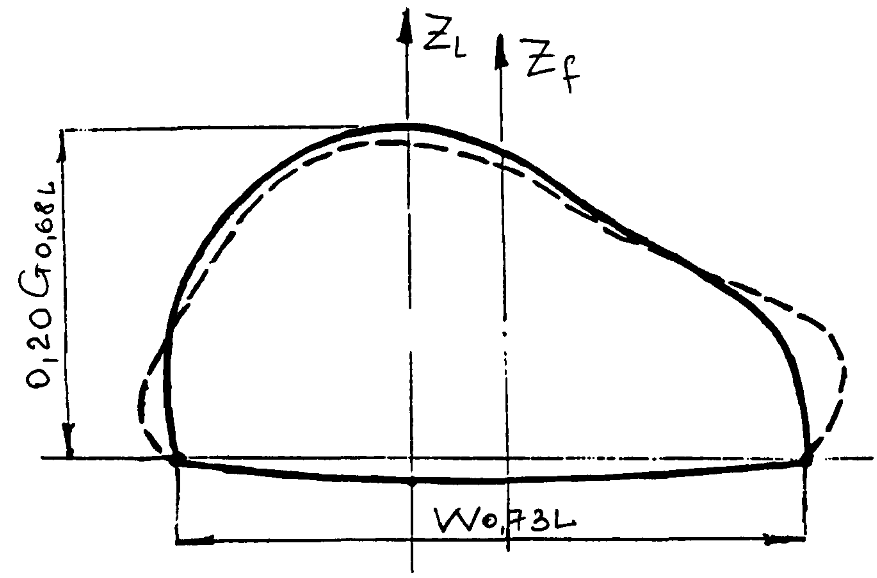


Fig. 5.11 The cross-section 0,73L design

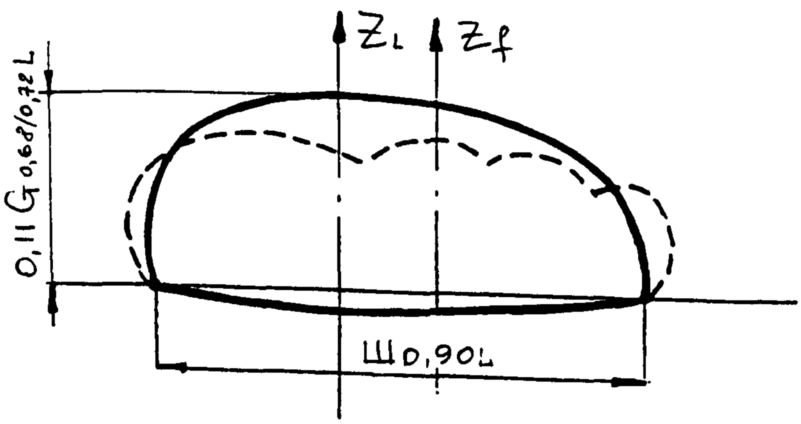


Fig. 5.12 The toe cross-section (0,90L) design

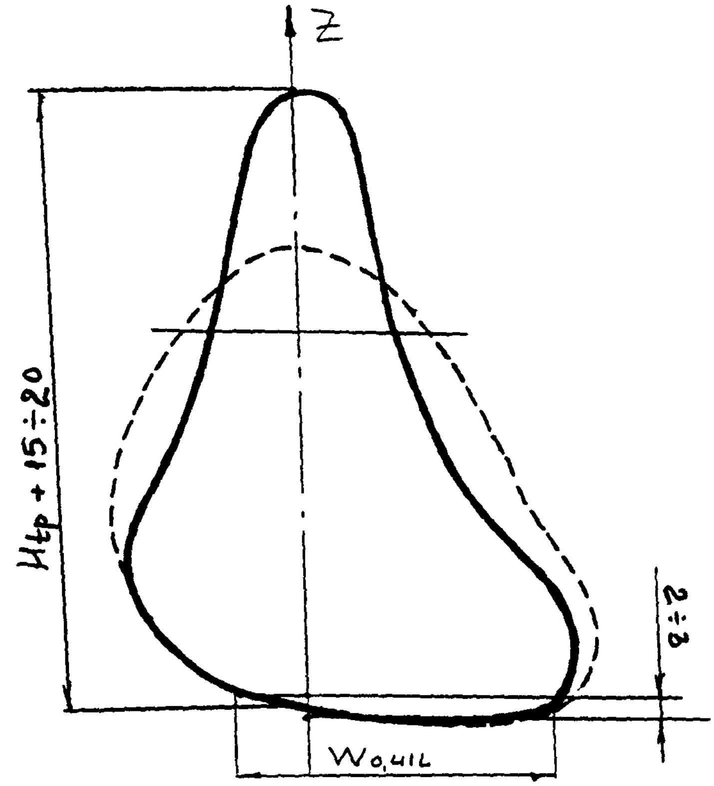


Fig. 5.13 The cross-section 0,41L design

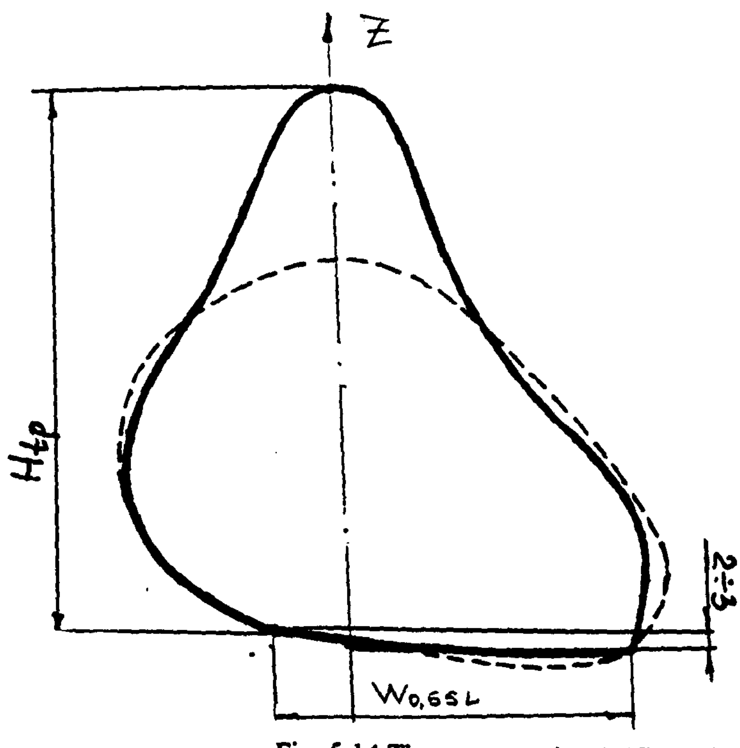


Fig. 5.14 The cross-section 0,55L design

Thus in a result of preliminary experiment a set of patterns of the last basic sections was developed, defects of existing techniques of last designing were revealed and the method of last designing in view of individual anthropometric data was elaborated.

5.3 Algorithm of designing individual last for ladies court shoes

The sequence of instructions for designing individual last for ladies court shoes has been developed and is presented below.

1. Obtain and process the foot plantogram (CHENTSOVA, 1974). In particular, draw the foot axis ***OXa*** passing through the centres of the seat and the ball joint (Fig. 5.6).

2. Orient the foot plantogram in the rectangular co-ordinate system ***XOY***. Thus the axis ***OX*** (a stick line of the last bottom pattern) diverges from the foot axis ***OXa*** under a corner 3° and will connect the distantly spaced points of the last bottom pattern in the toes and seat.

3. On the stick line postpone the segments 0.06L, 0.18L, 0.28L, 0.68L, 0.80L and 0.90L determining position of traditional cross-sections of the last. Values of segments are expressed as a percentage of the foot length (L). The alternative way is to find out the position of the widest places of the plantogram in the seat (0.18L) and ball joint (0.68L), end of the fifth toe (0.80L) and centre of the big toe (0.90L).

4. Define the position of a point ***a*** – the initial point of construction the bottom pattern. ***Oa = S = 0.02L + 0.05He.***

5. Define the position of seat axis of symmetry ***O'Xc***. ***OO' = 0.06L***. Draw a line ***O'Xc*** under a corner 7-9° from the axis ***OX***. An alternative way is to draw the seat axis of symmetry in the direction of the 3rd toes interval.

6. Define the widest place of the seat (or find the distance 0.18L postponed from the point ***O*** on the stick line ***OX*** – point ***O"***). Drop a perpendicular to the stick line. Measure the segment ***aO"***. This will be the radius to draw the seat shape in the back part passing through the point ***a*** till the points ***a'*** and ***a"*** between the imprint and the draft of the foot. ***O"a' = O"a"***.

7. Draw the bottom line symmetrically in relation to the seat axis of symmetry till the section 0.28L with gradual narrowing.

8. Outside of the symmetric part design the bottom pattern between the imprint and the draft closer to the imprint line.

9. Draw the outer line in the waist area coinciding with the foot draft.

10. Draw the inner line in the waist area close to the foot imprint, as the foot arch should be supported in this place by the footwear. However, do not bend the curve sharply in order to prevent folds when lasting an upper around the last.

11. In the ball joint area draw the contour between the draft and the imprint close to the latter but without narrowing within 15-20 mm.

12. On the stick line from the furthest toe point (point ***4'***) postpone the distance ΣP_i – the allowance including minimum allowance (*5 mm* - for ladies footwear) - and decorative allowance (0-30 mm or even more).

13. Design the toe shape according to the sketch of the last style taking into account the deviation corners of the big toe (α_1 *8-10°*) and the fifth toe (α_5); narrow forepart of the bottom pattern outside of the toes. Otherwise, narrow the forepart in the section ***0.80L*** for 9% and in the section ***1.10L*** for 20%.

14. Orientated the foot longitudinal-vertical section in rectangular co-ordinate system (Fig. 5.7) with the toes (from 0,68L section) located on the horizontal plane and the seat elevated to the necessary heel-height.

15. Define the heel point ***2*** on the perpendicular to the basic plane passing through the point ***a (Oa = S)***. Set the distance ***a2 = He***. Draw a heel curve contour through the point ***2*** and the most convex point of the foot heel curve (point ***1***), which is a smooth convex curve.

16. Continue the curve to the point ***12*** where the cone top plane begins. The distance between the points ***2*** and ***12*** of the cone top plane height and H_{tp} is equal to ***0.2L + 20 mm***.

17. Find out the point ***5*** – the point of normal allowance. Its co-ordinates are $x = L+5mm$ and $z = Ts = 0.067L-0.1He$, where ***Ts*** is the toe spring.

18. Draw the line (through the points ***1*** and ***5)*** that belongs to the basic plane of the last construction. Draw a curve in the back part of the profile bottom lower then the line ***1-5*** for 1.5-2 mm.

19. Find out the point ***3*** – centre of the foot bend. Its co-ordinates are $x = 0.73L$ and $z = 0.09L$. Connect the points 3 and 5. This will be the direction for drawing the bottom toe contour, which is a convex curve laying lower then the line for 1.5-2 mm.

20. Add a decorative allowance in the toe to the line ***3-5*** (point ***6***).

21. Rectify the profile of the bottom contour in the shank-ball joint area to the foot contour.

22. Locate the heights of the toe part of the profile that in the section ***0.90L*** (segment ***8-8'***) is equal to $0.11G_{0.68/0.73L}$ and in the section ***1.00L*** is equal to $0.09G_{0.68/0.73L}$.

23. Find the profile height in the ball joint section that is equal to $0.20G_{0.68/0.73L}$.

24. Find the length of the cone top plane that is equal to 0.41L (point ***10'***) or to 0.55L (point ***9***). The distance ***10-10' = 15-20 mm***.

25. Construct the profile contour.

26. Construct the cone top plane (Fig. 5.9). For this locate the length of the latter and define the position of the segments 0.07L, 0.18L, 0.41L and/or 0.55L. Restore perpendiculars in the points obtained and postpone the following distances on the perpendiculars to the both directions: 6/8.5 mm, 8.5/11.5 mm, 7.8/11.7 mm respectively (for the last with heel height 40 mm). Approximate the points.

27. To construct the contour of the seat cross-section (0.18L or the widest place of the foot seat) locate the height of the cone top plane (***0.02L+20mm***).

28. Define the location of the "***waist***" section on the height of the ball joint section ($0.20G_{0,68/0,72L}$).

29. On the appropriate perpendiculars (Fig. 5.9) restore four pairs of parameters: width of the cone top plane, width of previously designed bottom of the last in appropriate section, dimensional parameters (that are postponed at height of 15 mm from the internal party and 10 mm from the outside) and width in "waist" section.

30. Make a dip of the section bottom contour equal to 1,5-2 mm.

31. Determine the dimension of the ball joint section by the perimeter of a non-loaded foot, but its basis according to the imprint of a loaded foot and the last bottom pattern previously designed.

32. Locate the top part of the section higher then the foot (***0.20G***$_{0,68/0,72L}$).

33. Design the section featheredge on one level from the two sides (Fig. 5.10).

34. Construct the profile ensuring that the outside contour is concave, this is not be accurate since at lasting an upper does not contact withthe last in this place.

35. The perimeter of the last section should be smaller than one of the foot for *3,20-3,43 %* that is within the allowable limits of reduction of the foot ball joint girth due to the compression of the foot by footwear.

36. Design the section ***0,73L*** similarly to the section ***0,68L*** but taking into account the height of the given section accepted exactly equal to ***0,2*** of a perimeter of girth in section ***0,72L/0,68L***. Locate the featheredge on one level from both sides (Fig. 5.11).

37. Section ***0,90L*** passes through the imprint of the big toe. Therefore its height is equal to ***0,11*** of the girth perimeter in section ***0,72/0,68L***. Design this section similarly to the section ***0.73L***, taking into account the projected form of the toes of the last (Fig. 5.12).

38. Locate heights of the sections ***0,41L*** and ***0,55L*** (Fig. 5.13 and 5.14) that correspond to the end point of the cone top plane (flat design and with high instep respectively).

39. Transfer the bottom width parameters from the same parameters of the last bottom pattern. Thus, the outer point should be located 2-3 mm lower then the corresponding inner point. The widest places of the sections correspond to the foot

draft parameters. Draw the lower parts of the sections rectifying the foot section contours.

40. Design "waist" in the section ***0.41L***, which provides protection for the foot from flattening in the metatarsus-phalangeal joint. Narrow the top part of the sections.

41. Construct the section profile ensuring that the last sections are 3-4% smaller than the corresponding foot sections.

42. Define the location of the last featheredge through the bottom points of all cross-sections and the point ***a*** and ***6***.

Chapter 6. Methodology of numerical characterisation of last surface

Introduction

The need for a detailed description of surfaces is still a key problem in the field of computer aided geometric design. There is also a need to analyse the data collected from the work. Variants of these problems have been approached from many directions (KOMISSAROV and GORDEYEVA, 1996).

Although methods presented here deal with the problem, all break the surface into a series of surface patches. All commercial footwear CAD systems use different mathematical algorithms, many of which are poorly suited for the given problem.

6.1 Splines and Bezier curves (qualities and methods used)

For describing smooth curves and surfaces, vector and parametric forms are widely applied. The parametric representation of solids and curves is now an established tool in computer graphics, particularly in CAD. Techniques that were originally developed to model car bodies and aircraft shapes are now applied in the many diverse branches of computer graphics.

Although there are other ways of describing curves and surfaces, the parametric methods possesses distinct advantages over other methods where graphical display is required or where NC machines are used to manufacture such objects.

For example, points on the curve or surface may be readily computed sequentially along the curve or along parametric lines in the surface for display purposes. On the other hand, implicitly defined curves usually require the solution of a non-linear equation for each point, although using the previously computed points to make a good initial approximation at each step can accelerate this process.

Moreover, the computation of cutter offsets and similar related curves for numerical control purposes can also be much simpler when parametric methods are used. Another significant advantage is that translation or rotation of the axes or the object can usually be carried out by translating or rotating the vectors defining the curve, without modifying the functions of the parameters used (GRAY, 1993).

In the parametric case a point in space is defined as a column vector $r = [x,y,z]$, function describing the curve $r\ (U)$, where U is independent parameter. In comparison with the classical form $r = f\ (x,\ y)$, here equal status of co-ordinates $x,\ y,\ z$ is provided. It, in turn, provides an independence from a curve $r\ (U)$ situation relatively to co-ordinate axes $OX,\ OY,\ OZ$, and also allowing the description of closed contours.

For describing curves and wire-frames of objects it is enough to use one parameter, U, which characterises a distance along a curve from its beginning. When describing surfaces two parameters U and V and record $r\ (U,V)$ are used. The parameters U and V characterise a distance along a surface in orthogonal directions (forward, back, left or right). Recently the systems for modelling solid states made their appearance (GRAY, 1993), where three parameters $U,\ V$ and W and record $r\ (U,V,W)$ were used. This permits movement inside a solid state in orthogonal directions (ahead, to the side, up and down). Solid State modelling permits the description of changes to properties inside an object (for example, temperature or mechanical pressure).

For modelling a shoe last form it is enough to operate with curves $r\ (U)$ and surfaces $r(U,V)$. For this purpose, cubic polynomials are most frequently used, providing smoothness through the existence of the second derivative $r''_{UU}(U)$. An elementary segment is recorded as:

$$r\ (U) = U_0 + Ua_1 + U^2a_2 + U^3a_3 \qquad (6.1)$$

where $1 \geq U \geq 0$ (FAUX and PRATT, 1979).

A cubic segment can be computed by setting four vectors: points on the ends of the segment $r\ (0)$ and $r\ (1)$ and derivatives in these points $r'_U(0)$ and $r'_U(1)$ from the Ferguson formula:

$$r\ (U) = r(0)\ (1 - 3U^2 + 2U^3) + r(1)\ (3U^2 - 2U^3) + r'(0)\ (U - 2U^2 + U^3) + r'(1)\ (U^3 - U^2) \qquad (6.2)$$

By changing the location of $r'(0)$ and $r'(1)$, it is possible to influence the form of the cubic curve that connects the points $r(0)$ and $r(1)$.

The cubic segment $r_i(U)$ can form the basis for calculation of a spline. Thus $r_{i-1}(1) = r_i(0)$; $r_i(1) = r_{i+1}(0)$, and $r'_i(0)$ and $r'_i(1)$ are expressed for obtaining the curve smoothness. It should be noted that in the case of splines, the curves do not possess a local control property - a user can move only central points $r(U)$, and can not affect derivatives $r'(U)$. Thus, the flexibility of each segment is limited. Besides, spline requires complete recalculation when changing even one point.

Bernstein-Bezier curves and surfaces, or more briefly, Bezier curves and surfaces constituted one of the earliest attempts to develop a flexible and intuitive interface for CAD, that was implemented in the UNISURF surface design system developed by Bezier in 1972 for the Renault car company (FAUX et al, 1979).

The Bezier form allows the greatest degree of flexibility of a cubic curve by:

$$R(U) = (1-U)(1-U)(1-U)\,r_0 + 3U(1-U)(1-U)\,r_1 + 3U^2(1-U)\,r_2 + U^3 r_3 \quad (6.3)$$

where $r_0 = r(0)$

$r_3 = r(1)$

$3(r_1 - r_0) = r'(0)$

$$3(r_3 - r_2) = r'(1) \qquad (6.4)$$

Here vectors r_0, r_1, r_2, r_3 form a 'characteristic polyhedron' which descriptively shows a course of the curve $r(U)$ (Fig. 6.1). The patch is in sense an approximation to the polyhedron.

The configuration of the polyhedron gives the designer a good indication of the general shape of the corresponding patch, and modification of one or more of the vectors r_{ij} alters the patch in a predictable way. No gradients or twist vectors need be specified (FAUX et al, 1979). It has the great virtue as the system is therefore suitable for use by an operator with no advanced mathematical training.

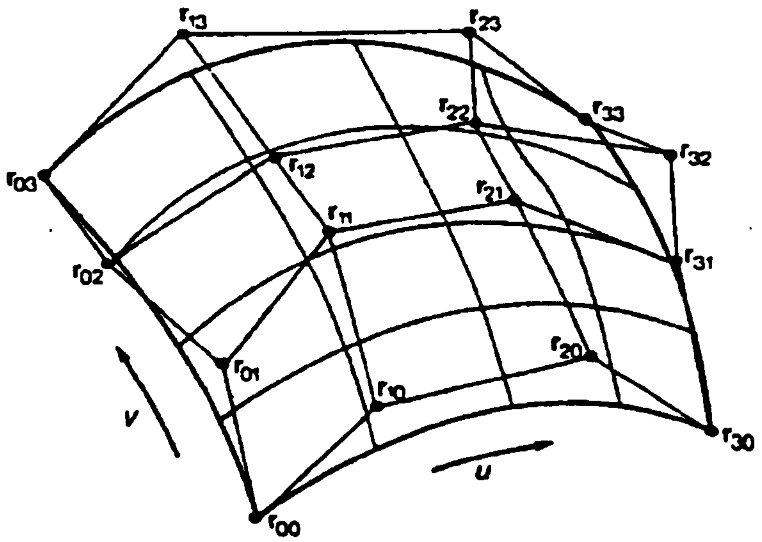


Figure 6.1 A "characteristic polyhedron" showing a course of the curve

The use of Bezier curves ensures smoothness for the inside of each patch of the parametric surface. As a single patch covers a significant part of the last surface, there is an opportunity to generate a smooth surface by updating a small quantity of patches by changing vectors r_{ij}. In the case of bicubic polynomial there are 16 of such vectors for each patch. Thus, the surface becomes controlled: it is important only to rationally decompose it for patches, i.e. to make the scheme of segmentation of a surface of simulated last. The movement of any one vertex alters the entirety of the surface, preserving its smoothness (HAGEN, 1992).

Hence, Bezier formula is convenient for hand-operated manipulating the path of a curve with the help of vectors r_1 and r_2, but user has to care about smooth joint with the next segments of a curve. Smoothness at the joint can be achieved, to a certain degree, by making use of the tangent property.

The equation defining each patch is

$$r(U,V) = \Sigma^{3}_{i=0}\ \Sigma^{3}_{j=0} (r_{ij} g_i (U)\ g_j (V));\ U \geq 0;\ 1 \geq V \qquad (6.5)$$

where $g_k{}^k(t)^{3-k} = (3!/k!(3-k)!)t\ (1-t),\ k = 0,1,2,3.$

The g_k are the cubic Bernstein basis functions. It is easy to check that $r(0,V)$ is a cubic Bezier curve whose characteristic polygon is defined by r_{00}, r_{01}, r_{02} and r_{03}; this curve is one of the boundaries of the patch. Correspondingly, the other three patch boundaries $r(1,V)$, $r(U,0)$ and $r(U,1)$ are curves of the same type (FAUX et al, 1979).

6.2 Comparison the Bezier curves with the B-splines

Advantages of spline (guarantee of smoothness of segments joint) and Bezier curves (free and convenient manipulation of a curve) are united in the B-cubic splining curves through known surface points. This is the usual method used in commercial CAD systems, the aim of which is to use a modified cubic that allows continuity across patch boundaries so that continuous style lines can be drawn. But the use of spline-interpolation while describing a surface requires 10^3 - 10^4 3D readouts and so modification of a spline-surface with known result is hindered because of the large number of knot points to manipulate. Also it is inconvenient to make, setting separately points or sections, as required to provide space smoothness of the surface.

That is why some of the engineering packages use Bezier curves and sometimes coons surfaces. The main disadvantage of the cubic is that unless the patches are even and rectangular they degenerate. This has particular significance at the toe and heel sections. This is because the patches tend towards triangles rather than rectangles. This is where coons and Bezier surfaces are better as they do not degenerate.

To prove this, a technique to transfer triangles into rectangles by adding additional vertex on the curve between two boundary knots so that the patch became smoother than before was developed by Goroch (GOROCH, 1996). In this work the shape of the toe section was compared with the real last toe shape, and they showed a high degree of correlation, thus confirming that the algorithm works well.

When comparing Bezier and B-spline curves it is sometimes said that B-splines are used in 2D but not 3D. In 2D they are appropriate as splining on the fly is often required. This is done by a system called ALIAS in 3D. In 3D, however, there is not enough control for practical use of B-splines.

The segment of cubic B-spline is calculated from the formula:

$$r_i(U_i) = 1/6\,[(-U^3 + 3U^2 - 3U + 1)\, r_{i-1} + (3U^3 - 6U^2 + U)\, r_i + (-3U^3 + 3U^2 + 3U + 1)\, r_{i+1} + U^3\, r_{i+1}] \qquad (6.6)$$

Here points r_i make polyhedron, evidently showing a course of a curve $r_i (U_i)$, where *1, 2,...i...n; n* are the segment numbers (HAGEN, 1992).

Nevertheless, in comparison with the Bezier form, changing the situation of one point r_i more complexly alters a curve as it has contact with four adjacent segments at once. Besides in contrast to Bezier curve here the points r_i do not lay directly on the curve $r(U)$, making control of a curve purely indirect.

To transfer to a surface $r (U, V)$ firstly they usually set boundaries of a patch as cubic segments $r (U)$ and $r (V)$ and then calculate continuous bicubic surface. Properties of splines, Bezier curves and B-splines for curves are similar to properties of appropriate surfaces. In this case the patch of Bezier surface is described by polyhedron with 16 vertices, four of which belong to the corners of the surface patch. In case of B-spline changing situation of one vertex alters the form of next sixteen patches. It means that for manipulating B-spline surface the latter should contain enough large number of patches.

6.3 Optimal mathematical algorithm for last surface description

When choosing mathematical methodology for describing the last surface, it is necessary to consider the following (KOMISSAROV et al, 1996).

The majority of the publications in the field of the mathematical description of curvilinear surfaces is aimed to create the most universal and flexible method. As a rule, it is B-spline on the basis of which majority of the modern programs for designing curvilinear surfaces is constructed. It is a matter of fact that B-splines allow the description of almost any shape and allow its simple modification. It gives large advantages for standardising methods and programs for two cases:

- when the surface is already determined and separate points of this surface are known (this takes place in some CAD systems for designing footwear using a last sample which is measured);
- when there is the requirement of creating only visual image without the need for high accuracy of a surface (it takes place in advertising, cinematography and making animated cartoon).

When designing a last without the prototype, i.e. on "an empty place", the problem is different. The basic difficulty is predictability of the surface behaviour in space and also the maintenance of fluency of curvature change without a change in a mark for large surface patches of the last.

These requirements are satisfied if the last surface is described by minimum number of initial data (patterns of contours). The form of representation of this data should be habitual for shoe manufacture and allow conscious management of the last surface. Thus, minimum number of elementary patches $r\ (U,\ V)$ describes the last surface, of bicubic surface, which determine the shape according to a mathematical formula. Of course, the smaller the number of patches, the larger the flexibility and curvature they should have whilst describing the last surface.

In this respect the Bezier curves is best as they provide the following:

- The greatest freedom and convenience of manipulation;
- Opportunity of direct setting the central points on spatial surface (as against from B-spline), that allows the precise definition of some important measurements;
- Opportunity to change conditions of smooth fitting to neighbouring patches while allowing a reduction of the influence of changes within one Bezier patch on the neighbouring ones in comparison with B-splines.

As was mentioned in previous chapters, the additional complexity of the problem is the lack of formal data and technique on last design. The lasts are designed manually using several patterns on the basis of hands on experience of the last stylist-maker.

A method of setting the surface by a set of sections, traditional for shipbuilding, is not appropriate approach for the last surface describing. The last surface is much more complex than in the case of the ship body and it is impossible to set arbitrary contours of large number of sections so that a surface in space will not have sinuosities.

When describing the last surface in CAD systems during last 20 years, the scheme illustrated in Fig. 6.2 has been used. Thus $r(U,V)$ is set as a grid of surface sections $r(U)$ and $r(V)$, and sections on one parameter (for example - U) are set close to a horizontal. Sections on other parameter are vertical and pass through the cone top plane.

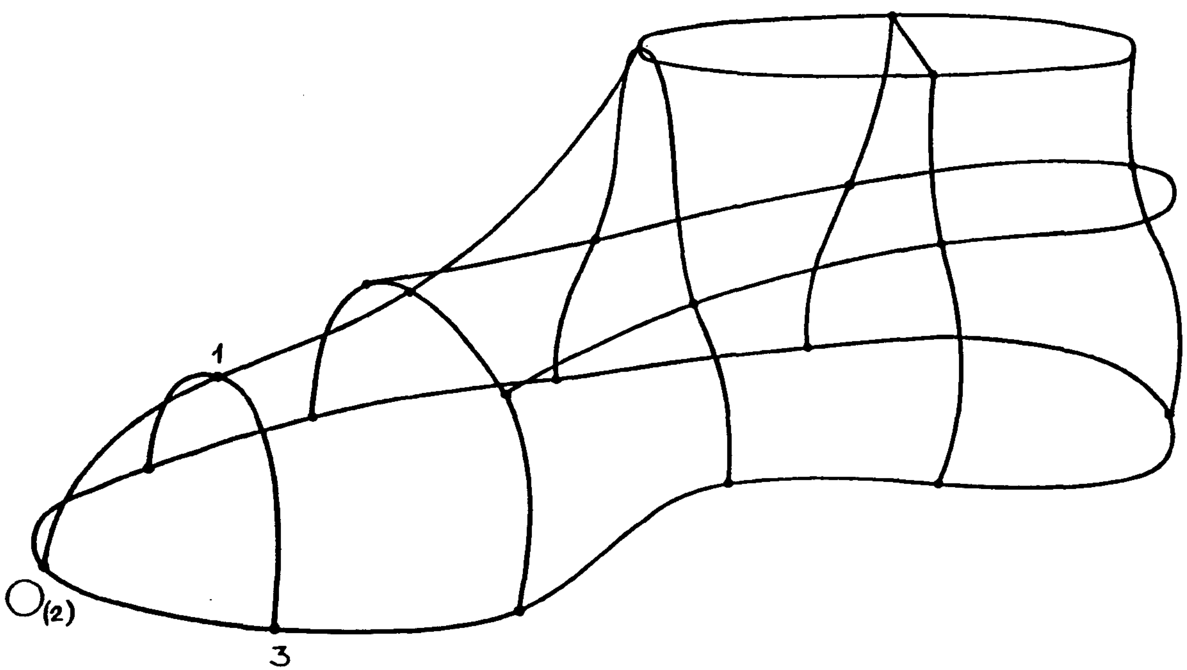


Fig. 6.2 A scheme of the last surface segmentation used in modern CAD systems

This scheme has appeared convenient for application of standard procedures of interpolation by parametrical splines of different types, as at enough density of the grid (at large number of central points of the grid ***r(U), r(V))*** the direction of ***U*** and ***V*** is almost orthogonal for each patch. Quantity of knots on the opposite borders of the spline is identical and they are located in regular intervals.

This scheme is designed for large number of central points, which are precisely measured on the physical last prototype. Without use of the data of measuring the prototype it is impossible to arrange all central points in the way, that allows spline to form a correct surface. If the last surface is set by B-spline, its updating in basic is possible by creation local convexities, but it does not allow creating the last without the prototype.

In 1992 Komissarov (KOMISSAROV, 1992) proposed the following method for solving the problem of the last designing without the prototype :

- the last surface is set by habitual for a shoe stylist contours of bottom pattern, profile and four cross-sections (these contours served as the boundaries for the patches of bicubic Bezier surface);
- the surface is described by a minimum quantity of the surface patches ***r (U, V)*** (it allows to guarantee surface behaviour inside each patch);
- it does not use spline but composite surface, and also for flexibility in updating each patch the requirement of continuity ***d"r/dU", d"r/dV"*** when sewing together is removed;
- sewing together boundary curves is made only with observance of collinearity $dr_i(1)/dU_i$ and $dr_{i+1}(0)/dU_{i+1}$ for adjacent curves $r_i(U)$ and $r_{i+1}(U)$;
- when calculating the surface ***r (U,V)*** angular derivatives are accounted as a vector sum of tangent vectors (derivatives ***dr(U)/dU, dr(U)/dV)*** to the boundary curves in the given corner of the surface patch ***r (U,V)***

$$d''r / dUdV = dr/dU + dr/dV \qquad (6.7)$$

- for convenience of independent updating the surface patch boundaries Bezier form for a cubic segment is used.

Fig. 6.3 illustrates the last framework offered by Komissarov where the surface is described by quadrangular bicubic patches, and in the toes by triangular patches. To construct a surface, 16 points are used, 12 of which belong to the boundary contours, and the remaining 4 are angular derivatives.

The example below shows the representation of a separate patch of the shoe last surface (last back part) as elementary bicubic segment.

Table 6.1 lists the co-ordinates of sixteen vectors r_{ij}, determining a patch of the last back part. In Fig. 6.4 an arrangement of vectors r_{ij} and the surface patch $r(U,V)$ in the Cartesian co-ordinate system is shown. By altering the tangent positions, it is possible to change the surface behaviour while preserving its smoothness.

Fig. 6.5 shows the result of modelling the last back part. The software is included in Appendix C.

r_{ij}	*x(mm)*	*y(mm)*	*z(mm)*
r_{00}	*9*	*10*	*65*
r_{10}	*9*	*67*	*65*
r_{20}	*12*	*67*	*65*
r_{30}	*12*	*10*	*65*
r_{01}	*11*	*10*	*35*
r_{11}	*11*	*67*	*35*
r_{21}	*18*	*67*	*23*
r_{31}	*18*	*67*	*23*
r_{02}	*42*	*10*	*21*
r_{12}	*38*	*72*	*21*
r_{22}	*47*	*73*	*17*
r_{32}	*33*	*10*	*17*
r_{03}	*32*	*10*	*0*
r_{13}	*28*	*72*	*0*
r_{23}	*31*	*73*	*0*

Table 6.1 Co-ordinates of vectors r_{ij}, determining a patch of the last back part

Thus, flexibility of the patch (and therefore the ability to describe as large surface patch as possible) of the bicubic surface in Bezier form is much better than of any segment described by a spline of any type. It also permits the creation of a continuous surface with minimum initial data.

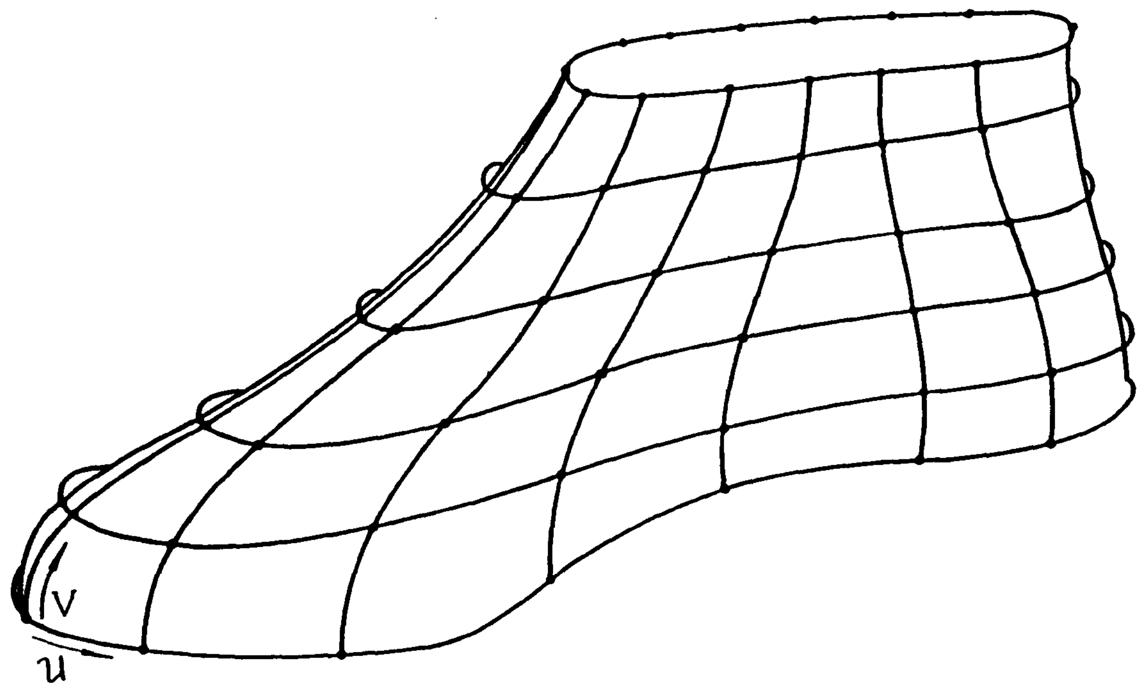


Fig. 6.3 A scheme of the last surface segmentation proposed by Komissarov

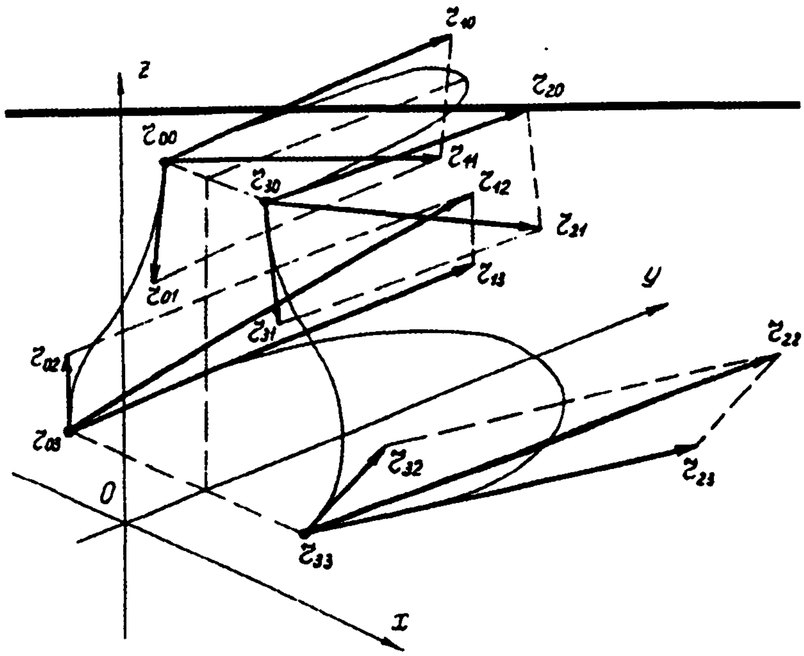


Figure 6.4 Arrangement of vectors r_{ij} determining a patch of the last back part in the Cartesian co-ordinate system

Figure 6.5 The result of modelling the last back part

The method offered was comprehensively investigated by Goroch (GOROCH, 1996) and was tested by describing a great deal of real lasts for different purposes. The experiments of Goroch consisted of the following:

- use of the most typical samples of the real lasts of Russian and Italian manufacture for men's, children's and ladies footwear with various heel-heights;
- the samples were measured at cross-sectional interval of *5 mm* with the help of special 3D digitiser for lasts designed by Komissarov (KOMISSAROV, 1992);

- the projections of the basic contours of each last were constructed according to the scheme shown in Fig. 1.1;
- these contours then were described by composite curves on the basis of Bezier segments, the coefficients of which were initial data for the last surface description;
- the patches of the continuous surface were then compared with cross-sections with a step of *5 mm* with the appropriate sections of the last measured before.

In result of the experiments the concurrence of contours with accuracy of *±0,5 mm* was achieved. It meets the accuracy of last designing under Russian Standard for lasts (FOOTWEAR LASTS. RUSSIAN STATE STANDARD No 3927-88, 1990).

The work of Goroch proved that the whole continuous surface (between the contours) will correspond to the real last shape if the basic last patterns contours are set according to the scheme described in Fig. 1.1.

However, the method is still in the stage of laboratory research as it has the following limitations:

- there is insufficient knowledge of the rules when transferring from a foot shape to the basic last contours;
- there is insufficient knowledge of the theoretically substantiated rules describing the basic last contour manipulation whilst designing;
- manipulation of separate points in 3D space is highly labour-intensive and unintuitive for a footwear designer.

Moreover, Goroch used existing prototype lasts and manipulated their surfaces and did not give any recommendations regarding how to set the surface when there was no prototype.

The above described method (KOMISSAROV, 1992) was chosen for generating the last mathematical model as the most appropriate for the purposes of the last surface modelling in view of individual anthropometric data.

Therefore, when designing a last without using a sample prototype, it is necessary, in particular, to overcome the following problems:

- when setting a frame-work of the surface (Fig. 1.1) an operator is to manipulate 3D data of each vector on appropriate projections; it is very difficult and requires special user interface and training the operator;

- aspects of updating the surface, initially connected to changing the heel height, are not considered;

- flat contour of the last front cone profile is used that does not correspond to reality and results in additional efforts when preparing data;

- the scheme of the last contours (Fig. 1.1) does not correspond to the location of control points of traditional lasts; it complicates maintenance of the last conformity with the particular foot.

All the problems listed have been overcome by the procedures of modifying the last form, described further in the work.

6.4 Generation of last mathematical model

In order to form a mathematical model of a last surface correctly; Goroch suggested the segmentation of the last surface by global parts presented in Bezier form (Fig. 1.1). To decrease the quantity of 3D information to be input when developing the software and to provide the convenience of manipulating the surface, the last orientation in the co-ordinate axes was carried out as follows.

The longitudinal last axis is ***OY***, the latitude one - ***OX*** and high-altitude - ***OZ*** (Fig. 1.1). The axis ***OY*** is chosen conterminous with a longitudinal axis of the last and the origin of co-ordinates placed so, that the heel point of the last is the most remote from the origin, and the toe point neighboring, but not conterminous with the origin of co-ordinates. The orientation of ***OX*** axis is carried out in view of convenience of generating and subsequent visualisation of mathematically defined last surface.

The direction "*+X*" is chosen in accordance with internal part of the last surface having a deflection in waist. This party is named **"LEFT-HAND"**.

The direction "*-X*", respectively, is chosen in accordance with the outside part and refers to as "RIGHT". A zero point on ***OZ*** axis is a projection of the point of contact of an insole profile in ball joint with ***OY*** axis onto this axis, provided that the horizontal patch of the back cone top plane is located in parallel to ***OY*** axes.

The choice of axis was based on the main consideration to simplify the creation of the continuous surface algorithms, modifications, co-ordinate transformations and other procedures. Hence, it was expedient to choose parameters such that the curves $R(U, V = const)$ lay in a plane parallel to the last slides (transverse-vertical sections).

These axis, then, are:

$R(U, V = const) \parallel XOZ$ - for transverse-vertical sections;

$R(U = const, V) \parallel YOZ$ - for longitudinal-vertical sections.

According to the scheme of segmentation, the skeleton of the last surface consists of the following contours.

The contours of the feather line and the cone top plane limit smooth patches of the last surface and their location are precisely determined. The back cone top plane lies in the plane parallel to ***XOY***, while the longitudinal-axial profile of the last lies in the plane ***YOZ***.

The location of skeleton slides is conditioned by the properties of the cubic polynomial. Research of the last surface with the purpose of its mathematical description allowed the selection of the most appropriate methods based on an analysis of the contours. One of the main properties of the cubic polynomial is the fact that the elementary curve described by the polynomial contains no more than one point that changes the mark of curvature. After the analysis of contours of transverse-vertical sections on this attribute, four sections and their positioning were chosen (Fig. 1.1).

As elementary surface patch should be limited from four parties by the curves set in Bezier form the necessity appeared to design additional longitudinal-horizontal section on the location of four-segment sections. The section depends on technological factors and heel height and characterises maximum concavity of contours of slides; therefore it was named "Waist".

To minimise the number of input data points, it is necessary to design the "Waist" contour lying in the plane parallel to ***XOY*** (Fig. 1.1) at the height of the joining point of transverse-vertical section in ball joint and the profile. Thus, the following scheme of segmentation of the last surface by transverse-vertical sections was used in the work. The last section in the back part (the section "Seat" at Fig. 1.1) finishes the Cone Top Plane parallel to the base axis.

The last section in the shank part, designated as "Shank", defines the end point of the top plane and the origin of the last front cone.

The last section in the ball joint, called the "Ball Joint", differentiates areas of four-segment and two-segment sections. This section is chosen in a place where the contour of the last feather line plane touches the longitudinal base axis OY.

The last section designated "Forepart" is located approximately in the middle of the area between the "Ball Joint" section and the end of the toe point. It is recommended to place it on the distance ***0.90L*** where the last standard toe section is.

Thus, the skeleton of the lateral last surface set by the curves in Bezier form is formed by contours of the bottom pattern, the longitudinal-axial section (profile), the top cone plane, the waist and four slides that limit zones with various formation.

This scheme of segmentation has the following positive characteristics:

- Minimum number of basic contours required;
- Selected mathematical method highly effective;
- Obvious formation of the surface skeleton;
- Co-ordination of the contours between each other that determines uniqueness of their forming and placing.

Such an approach permits the analysis of the last forming moulded parts and tooling working surfaces designing and grading for each zone independently.

The smooth surface is constructed out according to the data of the last skeleton contours taking into account the conditions of the segments co-ordination. When forming the 3D last surface skeleton, initially the node (basic) points of the contours are defined as being the points of elementary curve patch joints. Then, the vectors of parametric derivatives are set tangentially to the nodes. Changing the value of the derivative vector co-ordinates controls the curve contour.

The software requires that the data be submitted in a uniform format. Thus the co-ordinates of basic points and ends of parametrical derivative vectors of each contours are set in strictly determined order and have the names according to the system developed. The initial file reading is carried out in the following sequence:

- Co-ordinates of the nodes;
- Co-ordinates of derivative vectors in the starting points of the segments;
- Co-ordinates of derivative vectors in the final points of the segments;

Thus, the data of left-hand (internal) segment of the contour are read out first followed by the data for the right (outside) one.

For generating the basic points and vectors of contours the following designations are used:

pt0 [j]. [n] - starting point of segment ***j***,

pt1 [j]. [n] - final point of segment ***j***,

tn0 [j]. [n] - vector of initial derivative of segment ***j***,

tn1 [j]. [n] - vector of final derivative of segment ***j***,

where ***n*** - number of co-ordinate according to the scheme.

x = 0,

y = 1,

z = 2.

For the absolute definition of the data, each elementary contour patch has its own name in the file and the serial number in the program.

At the first stage a contour of the last bottom pattern (Fig. 6.6) is set. Going around the contours is carried out from the seat extreme point O_c to the toe extreme point 5. Thus, the following names and numbers assign the segments of the contour:

Patches 01 (0'1') – "BACK PART" - 0 (5),

Patches 12 (1'2') – "SHANK" - 1 (6),

Patches 23 (2'3') – "BALL JOINT" - 2 (7),

Patches 34 (3'4') – "TOES"- 3 (8),

Patches 45 (4'5) – "FOREPART" - 4 (9).

The extreme points O_c and 5 refer to as "heel point" and "forepart point" respectively.

Then the last profile contour is defined (Fig. 6.7). The basic patches of segments are named according to the bottom as follows:

Patch O_cO_m – "WAIST" - 10,

Patch O_mO_n – "CONE TOP PLANE" - 11,

Patch O_n1 – "BACK PART",

Patch 12 - "SHANK",

Patch 23 – "BALL JOINT" - 12,

Patch 34 – "TOES" 13,

Patch 45 – "FOREPART" - 14.

Four elementary segments form the contour of the cone top plane (Fig. 6.8a):

Patch O_n1 (O_n1') – "BACK PART" - 35 (40),

Patch 12 (1'2') – "SHANK" - 36 (41),

The basic segments of the waist contour is carried out in the following sequence (Fig. 6.8b):

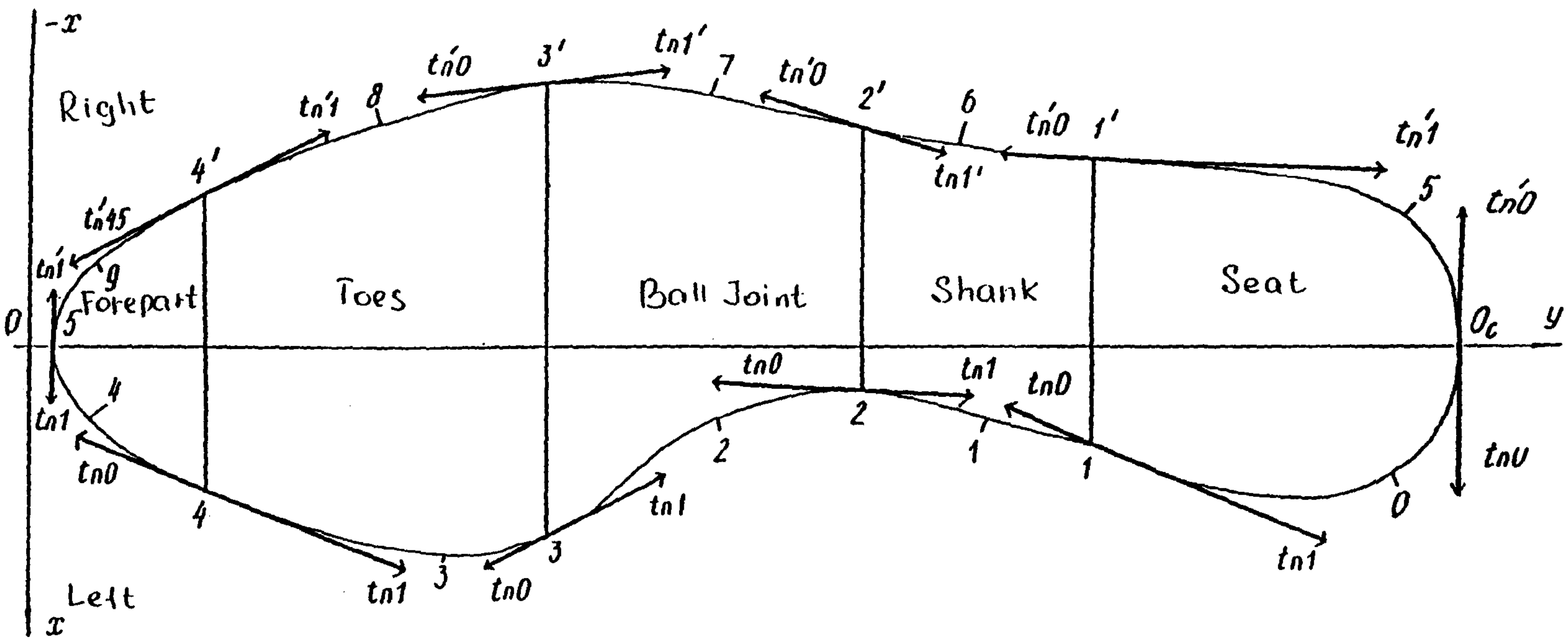


Fig. 6.6 The last bottom pattern generation

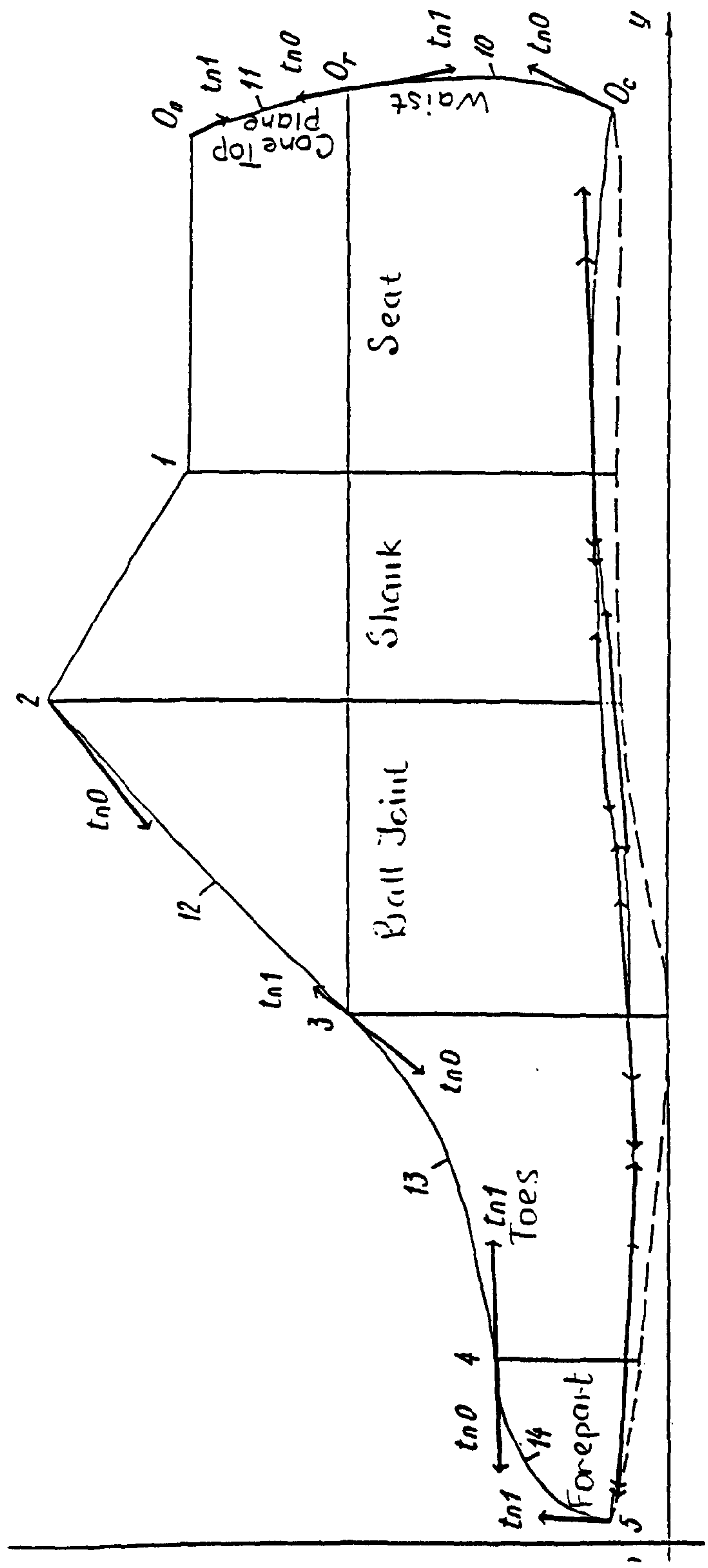


Fig. 6.7 The last profile contour generation

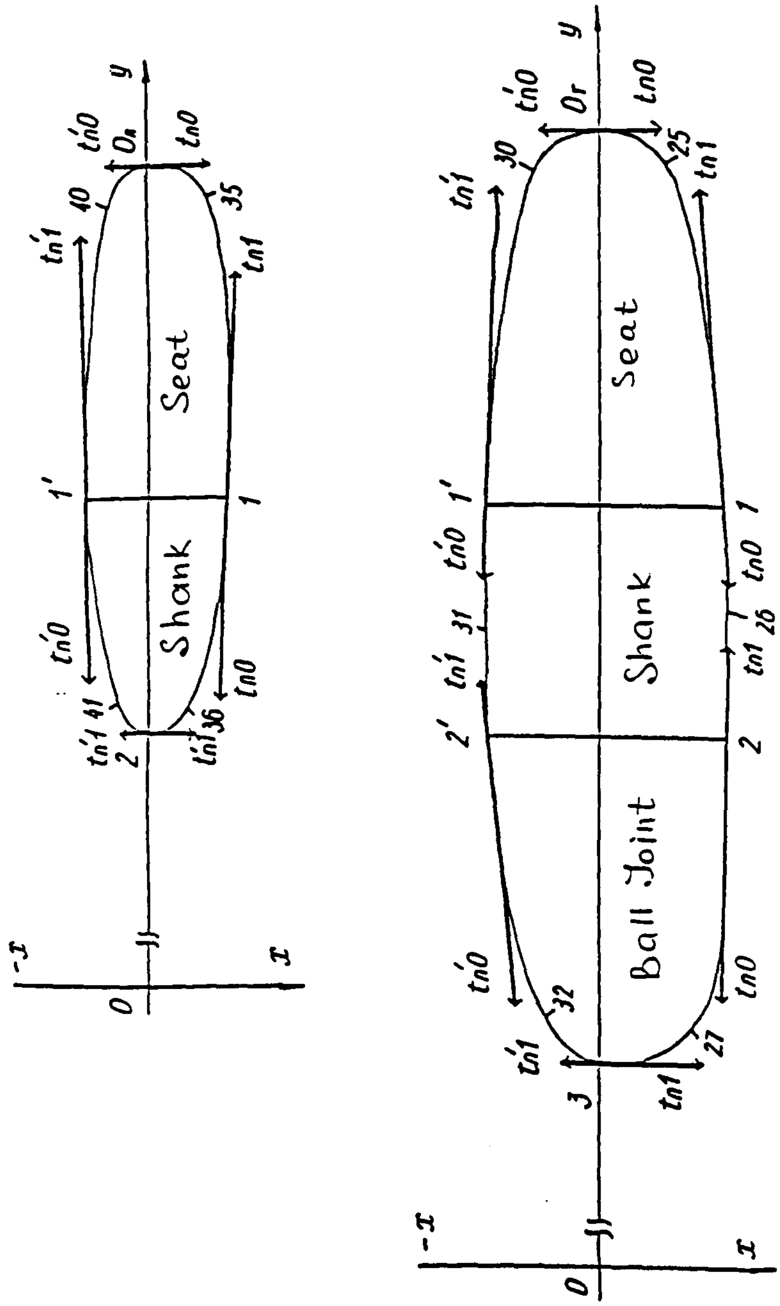


Fig. 6.8 The contours of the waist and the cone top plane generation

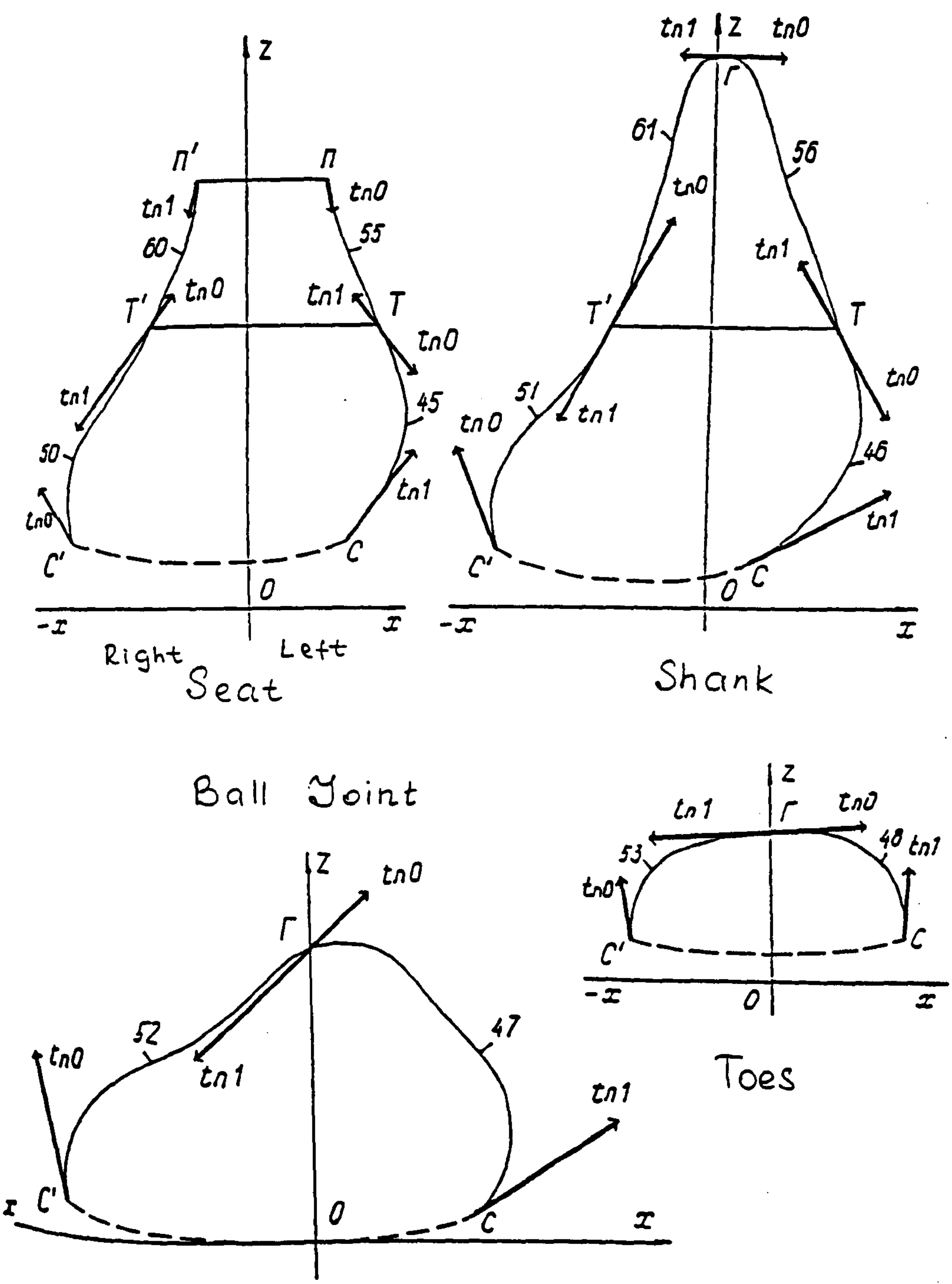


Fig. 6.9 Cross-sections generation

Patch $O_m 1$ ($O_m 1'$) – "BACK PART" - 25 (30),

Patch 12 (1'2') – "SHANK" - 26 (31),

Patch 23 (2'3') – "BALL JOINT" -27 (32).

The transverse-vertical sections of the borders of the patches are designated by the name of the appropriate zone. As to the moment of sections setting all the nodes are already determined only co-ordinates of the final points of derivative vectors are recorded into the data file. The sections "BACK PART" and "SHANK" are formed by four segments and sections "BALL JOINT" and "FOREPART" – by two (Fig. 6.9). Thus the bottoms segments 45-48 and 50-53 have the name "BOTTOM" and the top ones 55, 56 and 60, 61 – "FRONT CONE".

The data processing is carried out in a sequence determined by the number of a segment. After defining the contour skeletons, it is possible to set a continuous smooth last surface. Each patch of the surface limited by cubic segments in Bezier form can be designed on the formula:

$$R(U,V) = r(0)(1-U)^3(1-V)^3 + (dr(0)/dU)3U(1-U)^2(1-V)^3 + (dr(1)/dU)3U^2(1-U)(1-V)^3 + r(1)U^3(1-V)^3 + (dr(0)/dV)(1-U)^3 3V(1-V)^2 + (d''r(0)/dVdU)3U(1-U)^2 3V(1-V)^2 + (d''r(1)/dUdV)3U^2(1-U)3V(1-V)^2 + (dr(1)/dV)U^3 3V(1-V)^2 + (dr(2)/dV)(1-U)^2 3V^2(1-V) + (d''r(2)/dVdU)3U(1-U)^2 3V^2(1-V) + (d''r(3)/dUdV)3U^2(1-U)3V^2(1-V) + (dr(3)/dV) U^3 3V^2(1-V) + r(2)(1-U)^3 V^3 + (dr(2)/dU)3U(1-U)^2 V^3 + (dr(3)/dU)3U^2(1-U)V^2 + r(3)U^3V^3 \qquad (2.9)$$

where the nodes of each elementary patch, limited from four parties, have numbers ***0, 1, 2, 3***, and their co-ordinates are designated as ***r(0), r(1), r(2) and r(3)***.

For calculation it is necessary to co-ordinate the surface patches. The Fig. 6.10 illustrates the algorithm of work of the program LAST.EXE (see 7.3) realising the method of mathematical modelling of the last surface.

For the surface co-ordination the following actions are executed:

- Sewing together the points of adjacent segments of the contours (blocks 3, 6, 9, and 13);

• Sewing together the left-hand party of the contour with the right one (blocks 4, 5, 12, and 15);

• Joining the skeleton contours (blocks 7, 8, 16, 17, 19, 21, and 22);

• Additional definition of co-ordinates of nodes and derivative vectors through the basic points of other segments (blocks 10, 11, 14, 18, 20, 23).

A typical assignment of the boundary line values is shown for the example of the border between the patches 1 and 2 at Fig. 6.11 and is determined as follows:

$r_{013} = r_{002}; r_{131} = r_{102}; r_{232} = r_{202}; r_{331} = r_{302}$

The node points of the surface have a duality of boundary curves points. Thus, the definition of boundary flat curves gives 12 points. The points describing cross derivatives stay undetermined. Basically, the points of the cross derivatives can be left freely determined at the borders of the surface. The surface cross derivatives in adjacent knots are defined at the borders of the surface, which can be set by various manners. Use of the condition of defining cross derivatives as sums of partial derivatives is recommended as a starting point.

$$r_{221}= (r_{231}- r_{331}) + (r_{321}+ r_{331}) \qquad (6.10)$$

In this manner, an operator has no opportunity to manipulate the cross derivatives, thus guaranteeing the smoothness of the joint.

It is necessary here to note that according to the scheme of segmentation on the Fig. 1.1, at the place of joining the contours of the waist, profile and ball joint section, it is necessary to join six elementary bicubic segments instead of four. This results in an ambiguity of calculation of the cross derivatives responsible for the fulfilment of the surface smoothness condition. For observance of the surface smoothness it is recommended to use the variant of disconnected waist contour joining with the ball joint section contour suggested by Komissarov (KOMISSAROV, 1992) with use of procedures of co-ordinates calculation developed by Goroch (GOROCH, 1996).

1 Beginning
↓
2 Data file 3dlst.ini
↓
3 Reading the data array init.last
↓
4 Sewing together adjacent segments of the bottom
↓
5 Sewing together the left-hand and right parties of the bottom forepart
↓
6 Sewing together adjacent segments of the profile with gap on the cone top plane
↓
7 Sewing together the profile with the bottom back part
↓
8 Sewing together the profile with the bottom forepart
↓
9 Sewing together adjacent segments of the cone top plane
↓
10 Assignment of z co-ordinate to the points and derivatives of the cone top plane in accordance with z co-ordinate of the heel point
↓
11 Setting the height of final derivatives of the waist space patch
↓
12 Sewing together the left-hand and right parties of the waist back part
↓
13 Sewing together the waist adjacent segments
↓
14 Setting the waist height
↓
15 Sewing together the left-hand and right parties of the waist
↓
16 Sewing together the sections contours with the bottom at the left and right sides
↓
17 Sewing together the contours of sections with the waist at the left and right sides
↓
18 Assignment of y co-ordinates to the sections derivatives
↓
19 Sewing together the section "FOREPART" with the profile
↓
20 Assignments of y co-ordinate to the derivatives of the section "FOREPART"
↓
21 Sewing together the top segments of the sections except the section "FOREPART" with the waist
↓
22 Sewing together the top segments of the sections with the cone top plane
↓
23 Assignments of y co-ordinate of the bottom segments of the sections to the top segments
↓
24 End

Fig. 6.10 Algorithm of the last surface skeleton co-ordination

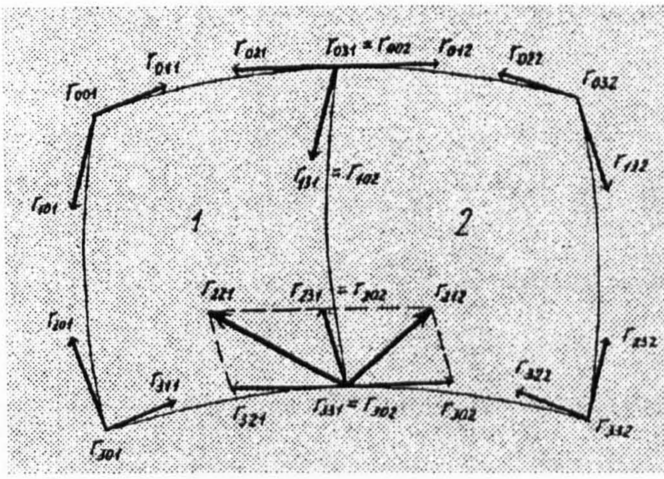


Fig. 6.11 Assignment of the boundary lines values

6.5 Development of new scheme of segmentation of the last surface

As mentioned above the scheme of segmentation offered by Goroch allows numerical generating the last model. However, the disadvantage of this scheme should be noted. The location of transverse-vertical sections "seat" and "toes" does not meet the standard situation of the basic sections of traditional lasts. This restricts the last conformity to the given foot. To overcome this problem new scheme of segmentation has been proposed in the work. The "Toes" section has been relocated to the location of the standard section ***0,9L*** and the "Seat" section - at the place of the standard section ***0,18L.***

However, in this case it becomes more difficult to set the end of the back cone top plane. Therefore, it is recommended to use such arrangement of the seat section for generating mathematical models of lasts with horizontal cone top plane (see 5.2.5). Since in the work the last for ladies court shoes has been developed, the form of the front cone profile is not of large practical significance, hence it is possible to use proposed modification of the last segmentation scheme presented on Fig. 6.12.

The section "Shank" is to be moved to the position of the end of front cone top plane, i.e. *0,55L* and the section "Ball Joint" is in its turn to be moved to the position of the standard section *0,68L.* This leads to relocating the section "Waist" lower in accordance with the place of connection of three last skeleton sections "Profile", "Ball Joint" and "Waist". This scheme of segmentation contains traditional for shoe designers contours and allows use of the individual last sections designed in the previous chapter.

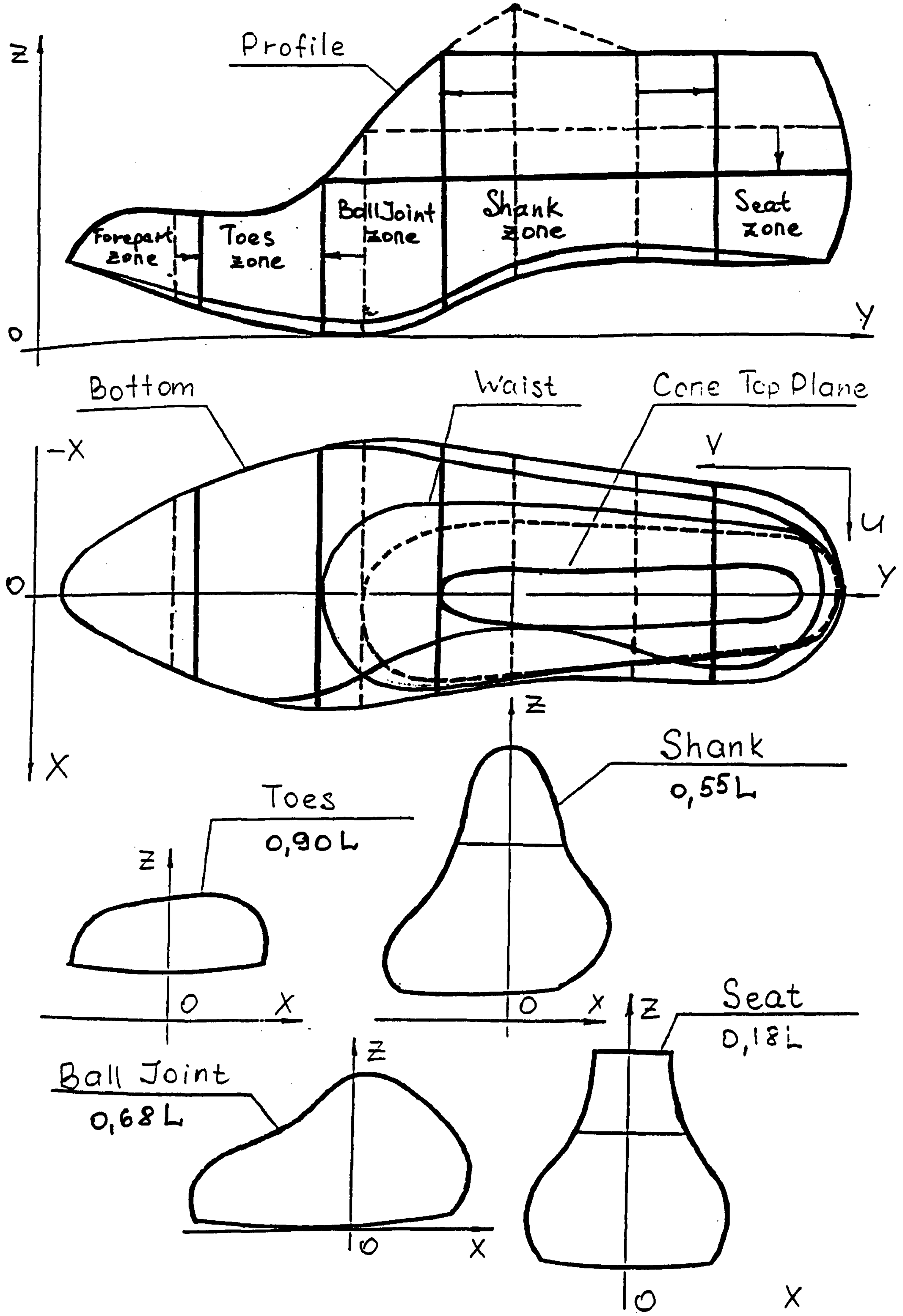


Fig. 6.12 The new scheme of segmentation of the last surface with horizontal cone top plane

6.6 Applying the method of mathematical modelling the last surface based on anthropometric data

Once received the foot data and developed a set of the last flat patterns (chapter 5), it is necessary to produce a numerical model of the last. The scheme of computer last modelling on the basis of anthropometric data is presented on Fig. 6.13.

1 Foot measurement
↓
2 Constructing projections of a bottom pattern, a profile and a cone top plane
↓
3 Choosing positions and constructing the last skeleton slides
↓
4 Constructing a horizontal section "Waist"
↓
5 Control of sections contours on a waistline
↓
6 Updating incorrect contours
↓
7 Generating a skeleton of last surface by vectors of parametrical derivatives
↓
8 Inputting data into the data file last.ini
↓
9 Starting the software
↓
10 Control of correct filling the data file
↓
11 Control of skeleton contours
↓
12 Control of surface smoothness
↓
13 Mathematical model of the last

Fig. 6.13 The scheme of computer last modelling based on anthropometric data

Computer modelling the last surface on the basis of anthropometric data begins with foot measurement. Then projections of the last sections are built (5.2) according to the scheme of segmentation on the Fig. 6.12 with subsequent generation of the last surface by vectors of parametrical derivatives (Fig. 6.14-6.17).

Fig. 6.18-6.19 illustrate the results of experiment of computer last surface modelling for individual foot measured that proves the possibility of application the method developed and validity of newly offered scheme of segmentation. Appendix D illustrates the data file for the last designed from this data.

Thus, the new scheme of the last surface segmentation and numerical methodology for on-screen design the last have been devised.

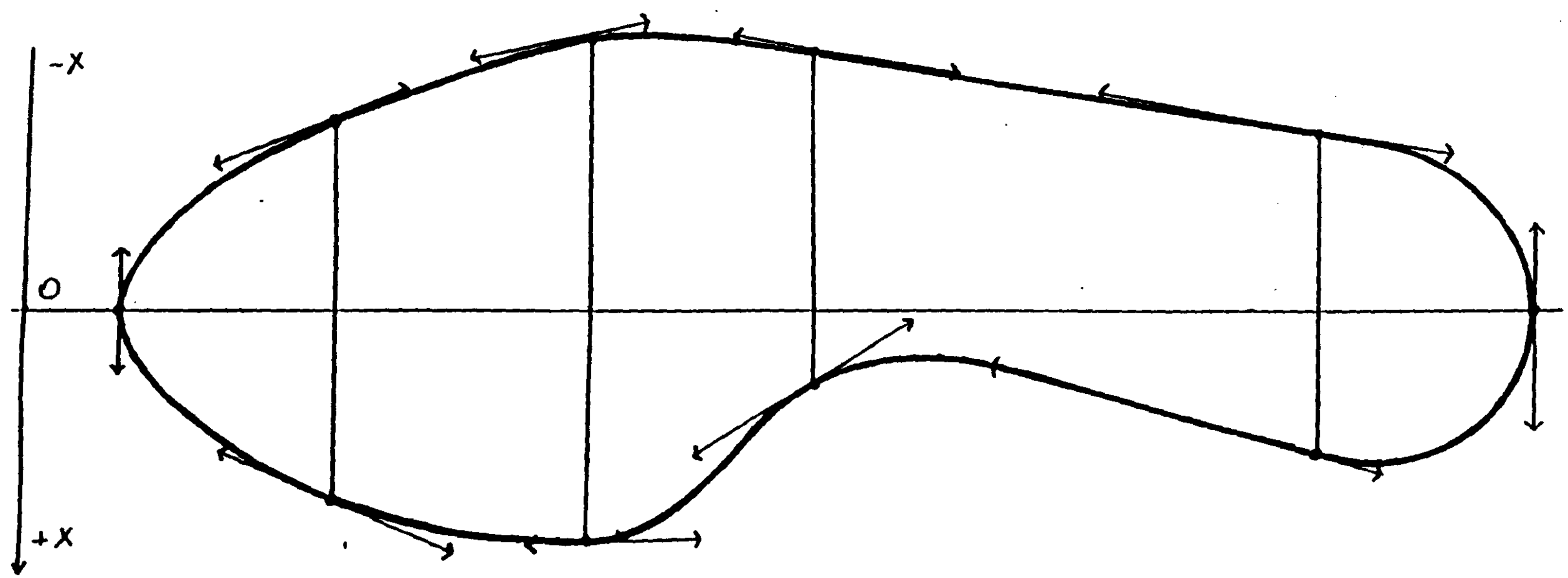


Figure 6.14 The individual last bottom pattern generation

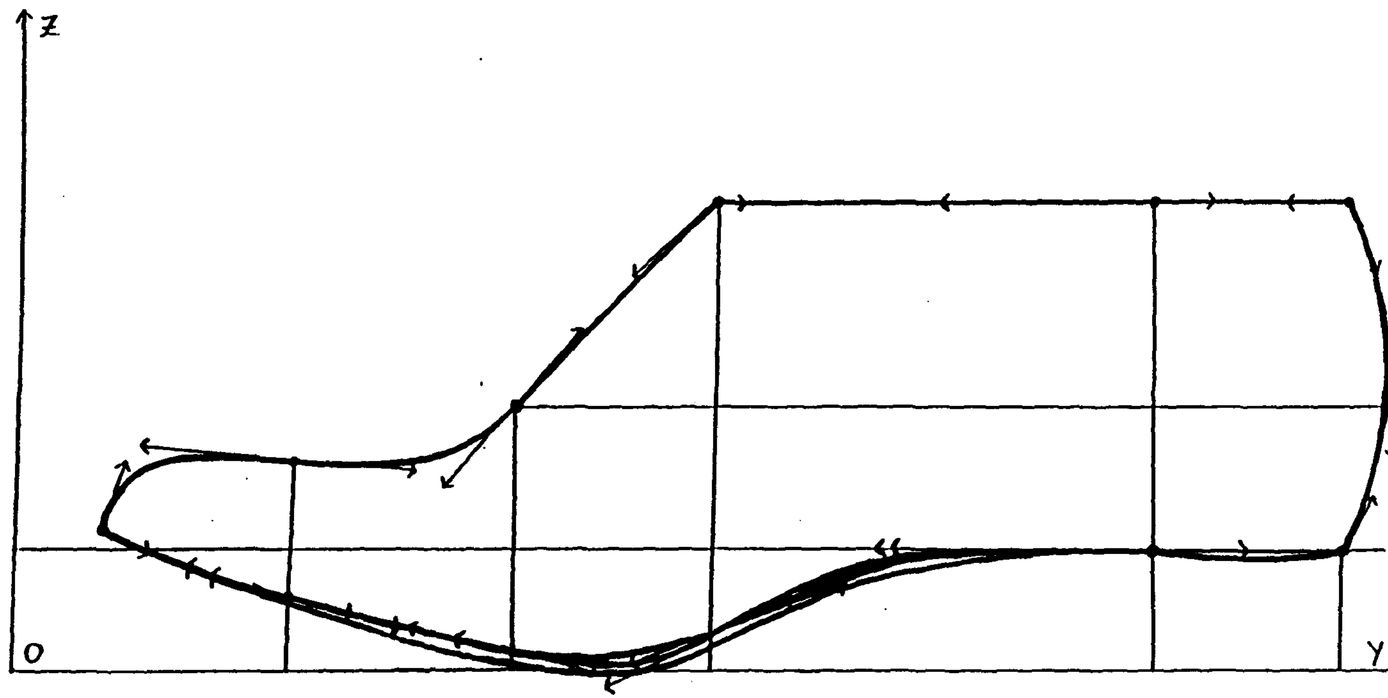


Figure 6.15 The individual last profile contour generation

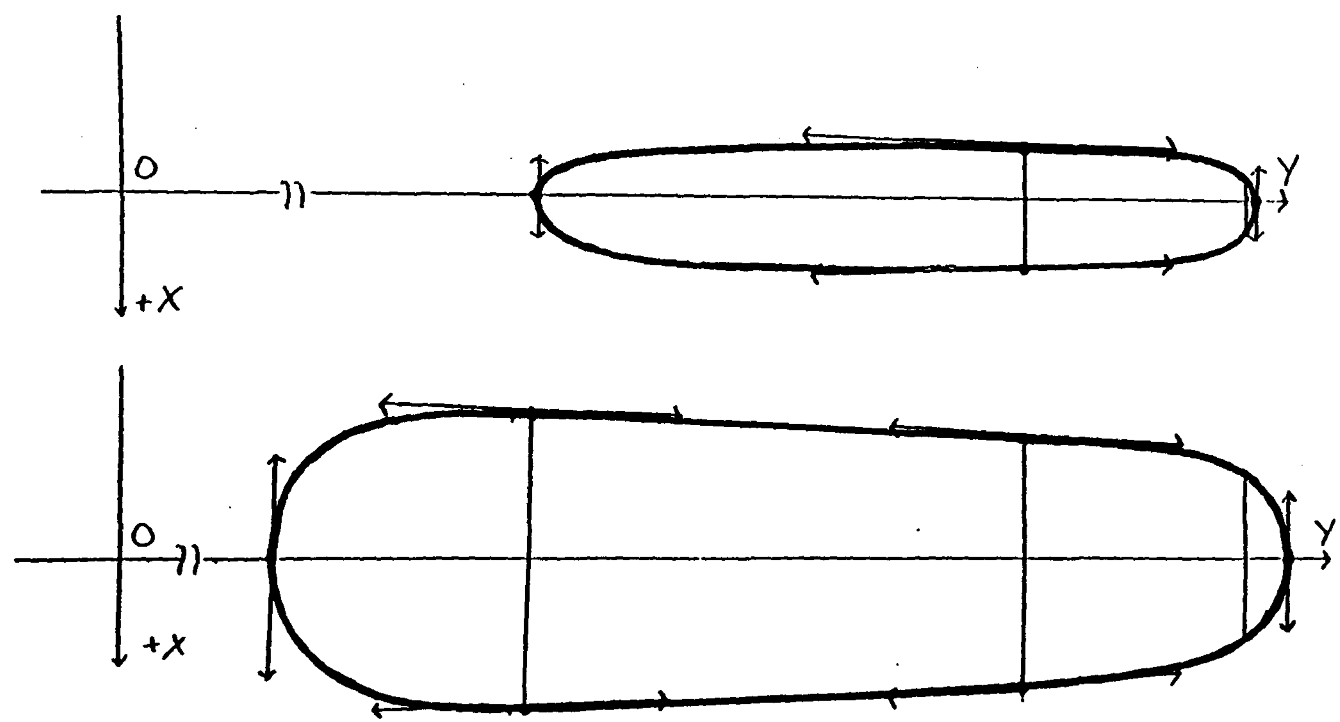


Figure 6.16 The individual last contours of the cone top plane and the waist generation

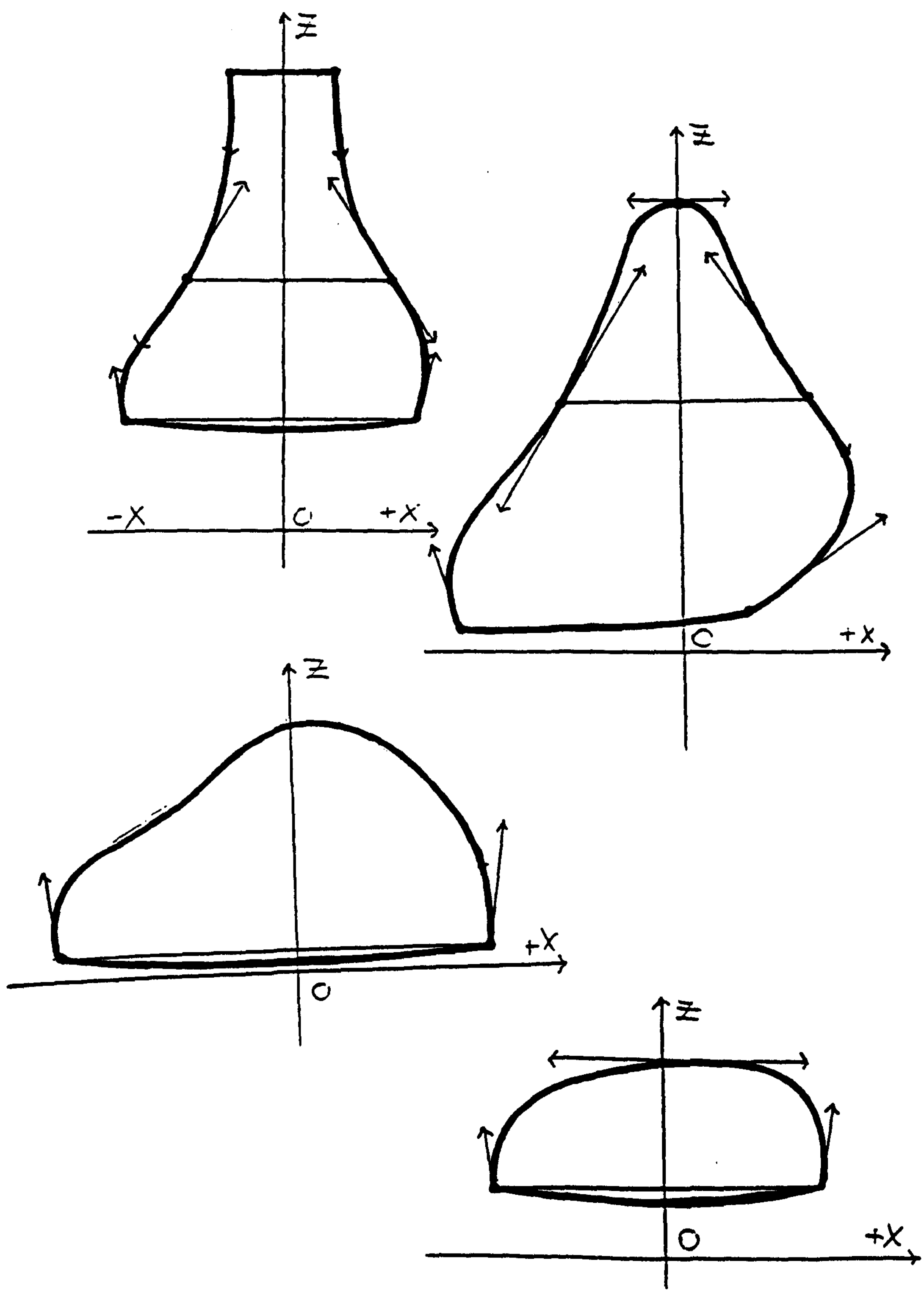


Figure 6.17 The individual last cross-sections generation

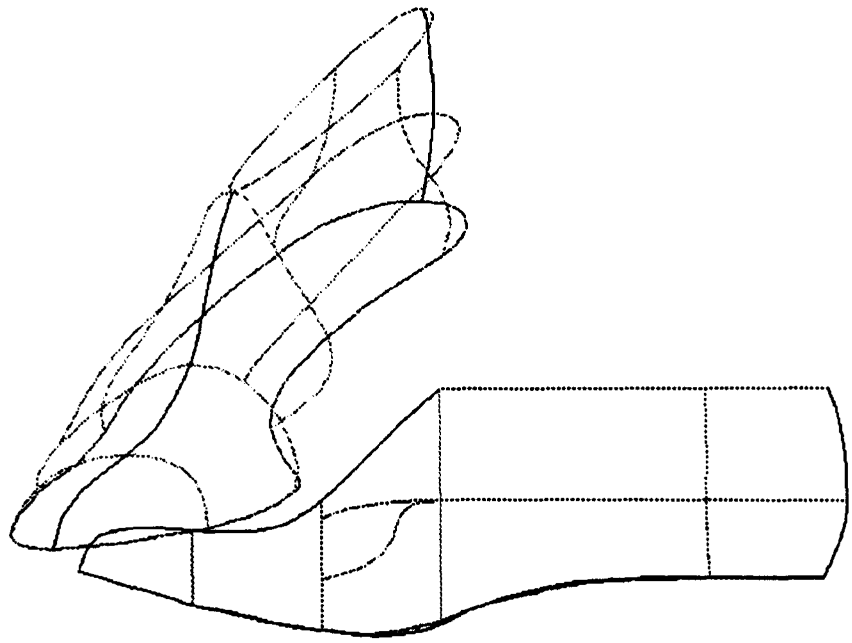


Fig. 6.18 Skeleton of the individual last

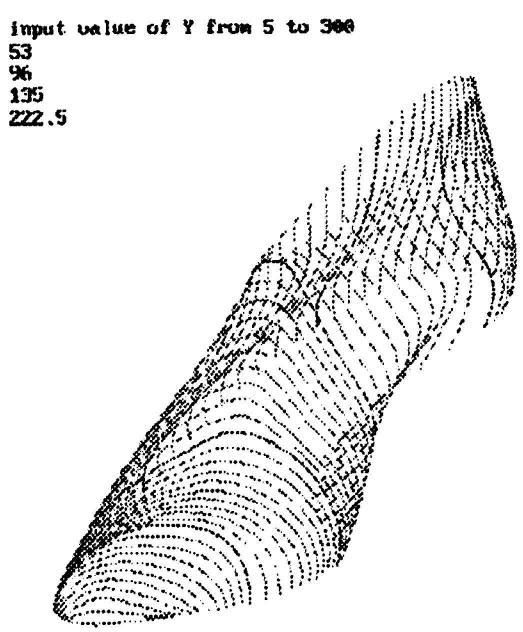


Fig. 6.19 Individual last surface

Chapter 7. Methodology of manipulation of last surface

Introduction

The optimal mathematical apparatus was chosen during preliminary experiments to study the possibility of the generation of the last model and the modification of its shape, on-screen, in an interactive mode.

For this purpose a sample of a last was chosen which was then measured with high accuracy (0.1 mm). The measurement data were used for construction of a skeleton of the last surface and for generating its mathematical model with use of the software developed (see 7.2). During the experiment it was necessary to establish laws for changing the last form while changing the heel height; to develop the list of possible modifications of the global patches of the last surface with the purpose of creating new last styles; to offer ways of modifying the last surface with changing the heel height; to test possible manipulations while changing the heel height from 40 to 80 mm.

An additional aim was to evaluate the application of general purpose engineering CAD software packages for the purposes of tooling-up designs. The MicroStation software package was chosen because of its flexibility and ease of use.

The scheme for realisation of intermediate experiments is indicated below (Fig. 7.1).

7.1 Foot and last sizing device and measuring the last

For the experiment, a last of style *No 873* for court shoes with the heel height 40 mm made on Italian analogues at "ALBA" factory, known for making rather qualitative and good-fitting lady's footwear, was chosen. The last was tested at manufacture to establish that it had good fit qualities.

The last was measured by means of a last measuring device, which structurally consists of two main parts: the jig and the tracking system. The mechanical device ensures fastening, basing and moving of sample last, while the tracking system tracks

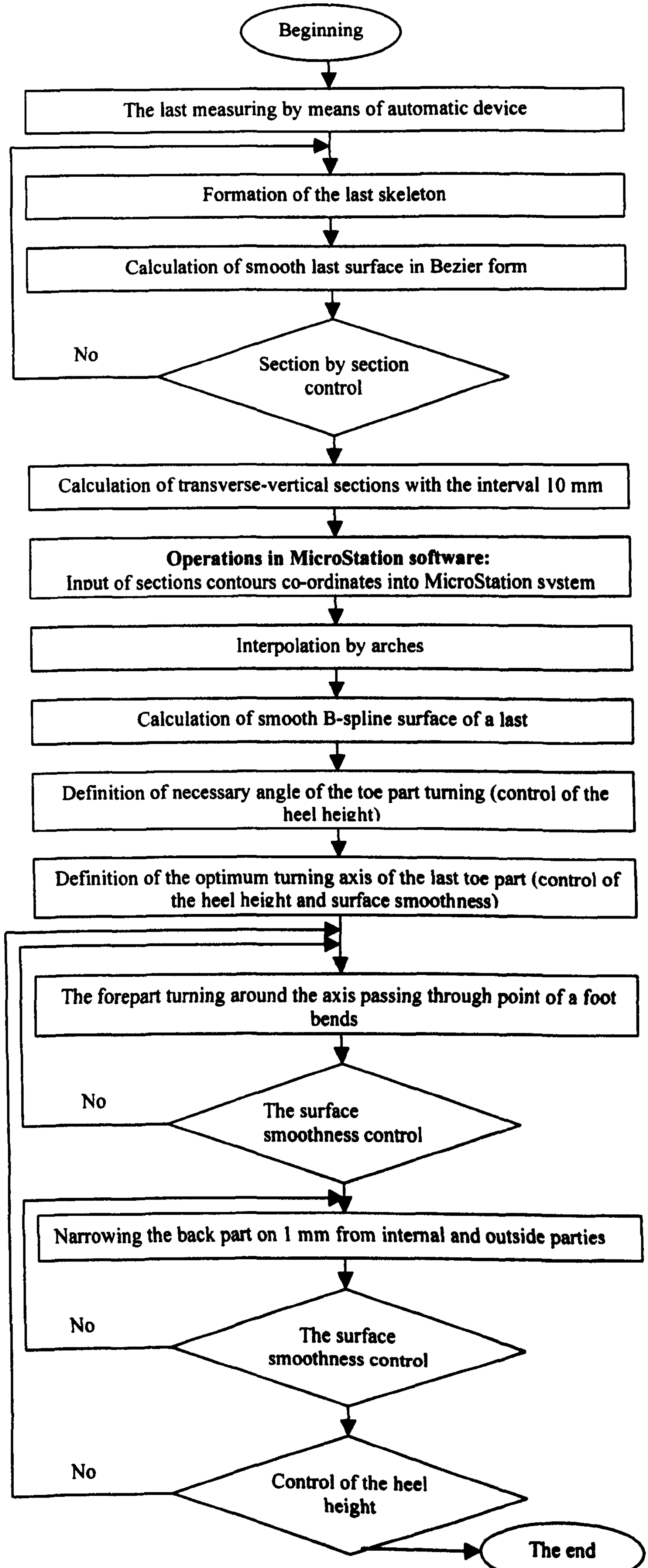


Fig. 7.1 The scheme of realization of preliminary experiment with use of MicroStationsoftware

geometrical parameters of teh surface by contact. These measurements are recorded on the recordingmeasuring equipment that is connected to the device by a cable, as shown in figures 7.2 and 7.3.

The device made as a table on the top of which elements of the measuring device are mounted includes the frame **1** on which guides **2** with driving screw **3**, and also units for fastening and rotating the last to be measured **4**, are located. In the guides **2** the carriage **5** has an opportunity of moving with the help of driving screw **3**. The toe part unit **6**, that fastens the last, contains gauges of angular movment of inductosyn type **7** established onto the rotation axis of the last **4**. The seat unit **8**, that fastens the last, contains a stop **9** with the possibility of fixing the position **12** that operates with each $5°$ rotation of the last axis. The carriage **5** allows anglular measrement using pointed test probe **13** and moves with the help of the driving screw **3** from a flywheel **14**, which is turned by a handle. The position of the carriage is measured by a linear inductosyn **15** installed on the arm. In the guide cartridges of the holder **16** the mobile test prod **13** is established. The terminator **17** carries a probe, which establishes each location of the probe **13** in relation to the holder **16** with the help of the spring **18**. The limitor **17** and the holder case **16** serve as elements of a contact indicators; the terminator **17** is isolated from the probe **13**. The linear inductosyn **22** established on the carriage **5** serves to measure the location of the probe.

The device for digital indication includes the gauges of the three co-ordinates **7, 15, 22,** connected by amplifiers **23-28** with devices for digital indication of movement **29-31**. The device is also supplied with a means of standardising the last position **33** and the positions of the fixing arms.

The object to be measured **4**, for example, a shoe last, is located in the units fastening **6** and **8**. Simulatneous movement of the last **4** and the probe **13** is carried out with the help of flywheels **11** and **14**. In order to determine a point on the surface, the test probe **13** is driven to the last with the help of the handle **21** and at the moment of contact the contact gauge **17** begins to operate. The devices **29, 30, 31** store the current values of three co-ordinates of the device positions which can be read out from the gauge **17**. Before measuring, it is necessary to record the values of initial locations into the units **29, 30, 31** with the help of buttons **"0"** or **"n"**.

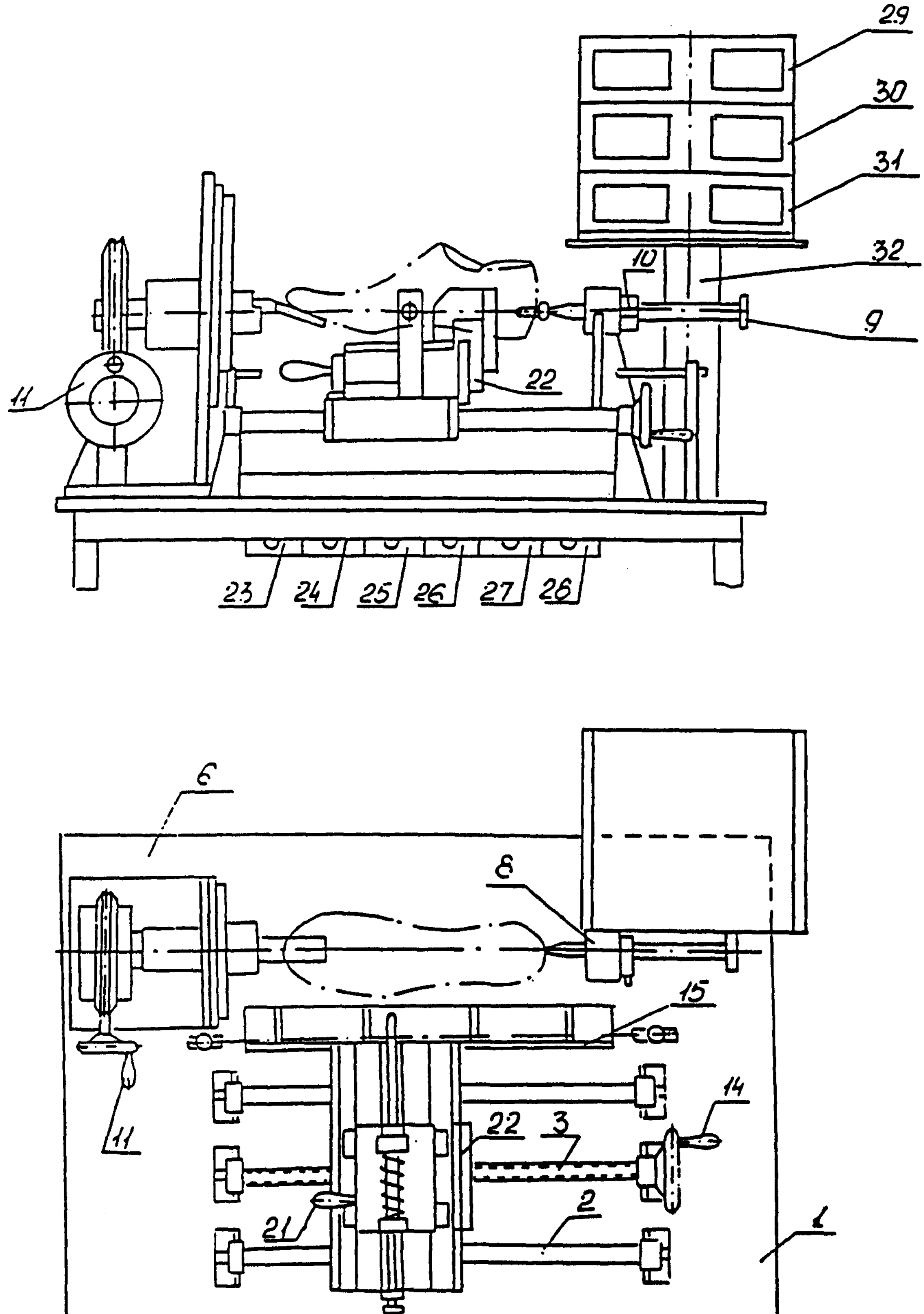


Figure 7.2 A general view of the last-measuring device

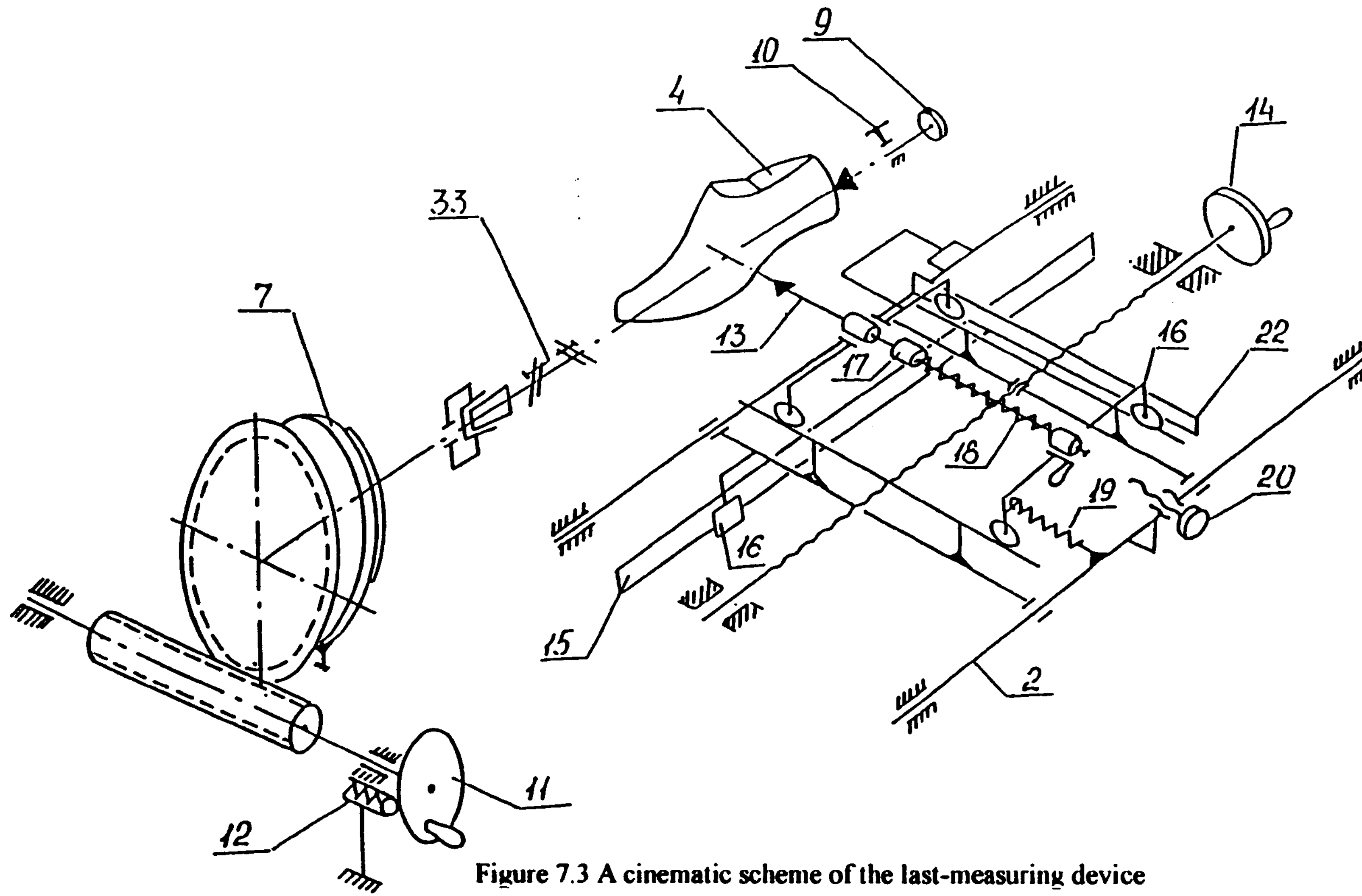


Figure 7.3 A cinematic scheme of the last-measuring device

The exact positioning and installing the last in the starting position is executed with the help of a device **33**. In these positions of the last and probe, they establish the initial position by pressing the button **"0"** for blocks of ϕ and z co-ordinates and button **"n"** - for the block of R co-ordinates.

In order to measure the cross-sections using the flywheel **14** the required last section is chosen, and movement around the surface is made with the help the flywheel **11**. To measure the required point of the section the probe **13** is driven to the point with the help of the handle **21** until it contacts the last surface.

Before measuring the last, it is necessary to draw the following lines onto its surface - the longitudinal-vertical section connecting the extreme points of the bottom in the back part and in the forepart, the extreme points of the back part, of the cone top plane and of the toes. For the correct location the last in the measuring device they mark the most forward point of the heel curve located on 1/3 of the heel curve height; this point serves for fixing the seat unit. The toe unit of basing the last uses three screws so disposes that the marked longitudinal axis of the bottom passes through the centre of one of the screws and between the centres of the other two.

Positioning the last in the measuring device is carried out as follows. The position of the longitudinal axis of the bottom should correspond to $0°$ as indicated by the gauge **7** (Fig. 7.3). The extreme point ***On*** of the cone top surface (Fig. 7.4) locates $180°$ position for the angular movement gauge. Thus, the side points of the cone top surface P^{os} and P^{in} located on the ends of the horizontal part of the cone top plane should lie at the same height as the point ***On***. For correct definition of the co-ordinates of the given points, in the polar co-ordinate system the following points are calculated:

$$R_n^{in} = R_0 \sin \alpha$$

$$R_n^{os} = R_0 \sin \alpha \qquad (7.1)$$

Where R_0 - R co-ordinate of the point O;

R_n^{in}, R_n^{os} – co-ordinates of the points P^{in} (inside) and P^{os} (outside) respectively;

α - the corner of turning, °.

The additional condition is the position of the ball joint marks at position H^{is} and H^{os} (Fig. 7.4).

The measurements are made in sequence from the heel point O to the last toe extreme point O_t taking the line of the longitudinal axis of the bottom as $0°$ level, with step size appropriate for comprehensive definition of the last surface. For ordinary measurements the usual step size is considered to be equal to 10 mm, however, for research purposes a step of 5 mm (especially for ball joint part) is used. Besides this, it is necessary to get the measurements of co-ordinates and sections, which correspond to the location of the following points:

1. The heel point O;
2. The origin of the cone top plane On;
3. The ends of the back cone top plane (P^{os},P^{in});
4. The end of the cone top plane G_p;
5. Marks in the ball joint H^{os}, H^{is};
6. The toe extreme point O_t;
7. The feather line points;
8. The cone top surface edges points;
9. Other marked points;
10. Points belonging to the spacial location of the front cone profile.

The array of the last surface measurements is recorded into a table for further processing. The data processing consists in construction of section contours in polar co-ordinates with negligible errors. The individual deviations of co-ordinates of section contour points are corrected within the tables.

Tabulated data of the last measurements of the model *No 873* are indicated in Appendix E. From the data obtained, transverse-vertical cross-sections were constructed. In the case of discrepancy of the measurements the tabulated data were corrected in

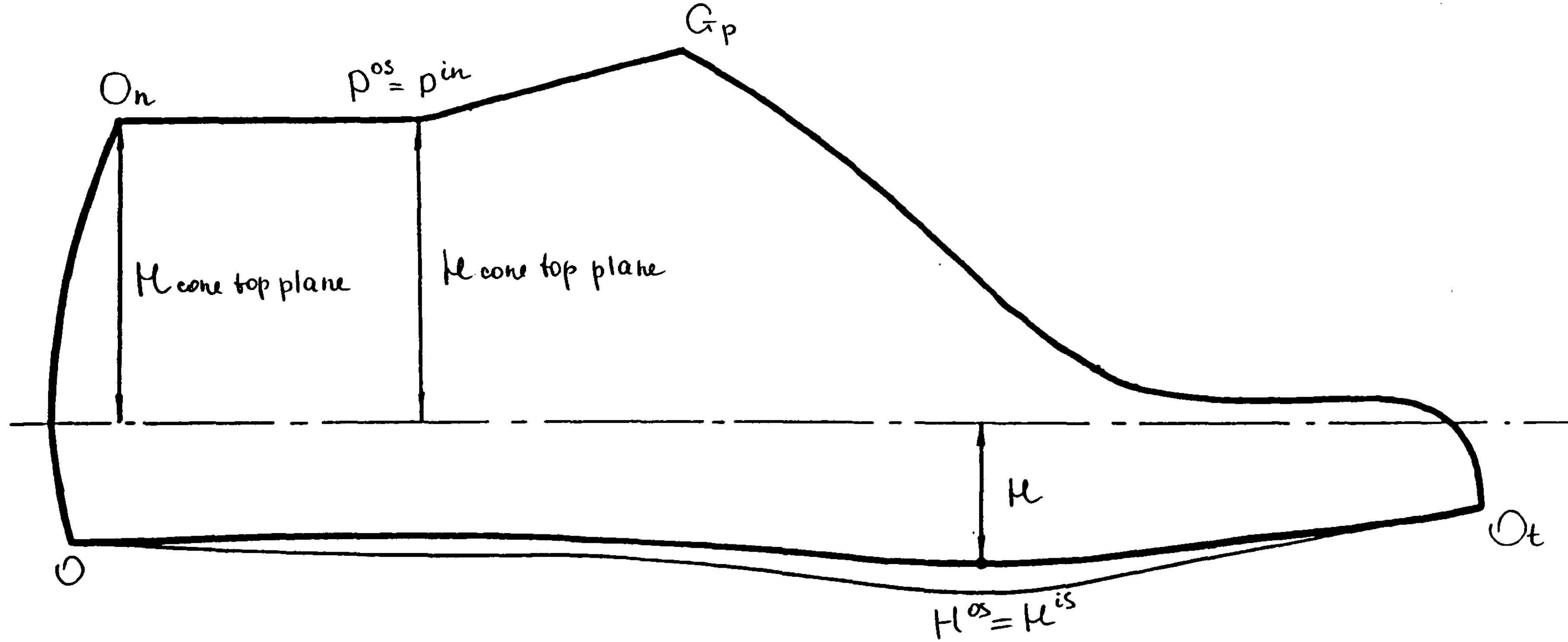


Figure 7.4 Positioning the last in the measuring device

accordance with the image of these sections. Pursuant to the item 6.4 and the scheme of segmentation illustrated on the Fig. 1.1 (as the object of the experimentation was a ready made last with standard cone top plane) the node points and derivative vectors were set in order to create the last skeleton and generate its mathematical model (Fig. 7.5-7.9). The data file is indicated in Appendix F.

After adjusting the sections of the last surface mathematical model to correlate with the sample last sections of the same name, within an accuracy of 0.5 mm, the co-ordinates of intermediate transverse-vertical cross-sections of the mathematical model were calculated at 5-10 mm intervals. The data were then imported into the MicroStation software with the purpose of manipulating the form of the initial last.

7.2 Possible last surface modifications

With the purpose of defining the principles for last manipulation, lasts of different types and forms were investigated. The aim was to characterise differences in geometrical parameters of the ready-made lasts of similar styles but with various heel height (in particular, 40 and 80 mm). It was necessary to empirically define the changes of the last form at changing the heel height. For this purpose the best-fitting lasts of domestic and foreign manufacture were selected and comparison of their base sections (bottom pattern, profile, seat and ball joint cross-sections) were conducted.

Comparison analysis of the shapes of the real lasts for court shoes with various heel elevation conducted during this work has revealed shape alterations as follows:

- back part shape - the higher the heel, the narrower the back part (to narrow the seat for 1/2 mm for each extra 20 mm of heel size);

- heel curve - the lowest 1/3 part of the heel curve alters according to the extent of shift of the last bottom (S) with respect to the heel point; the value of S is defined under the formula: $S = 0{,}02L + 0{,}05\ He$ (with an increasing heel height of *10 mm* the shift is increased by *0,5 mm*);

- in relation to the above the bottom pattern length changes to take into account the shift value;

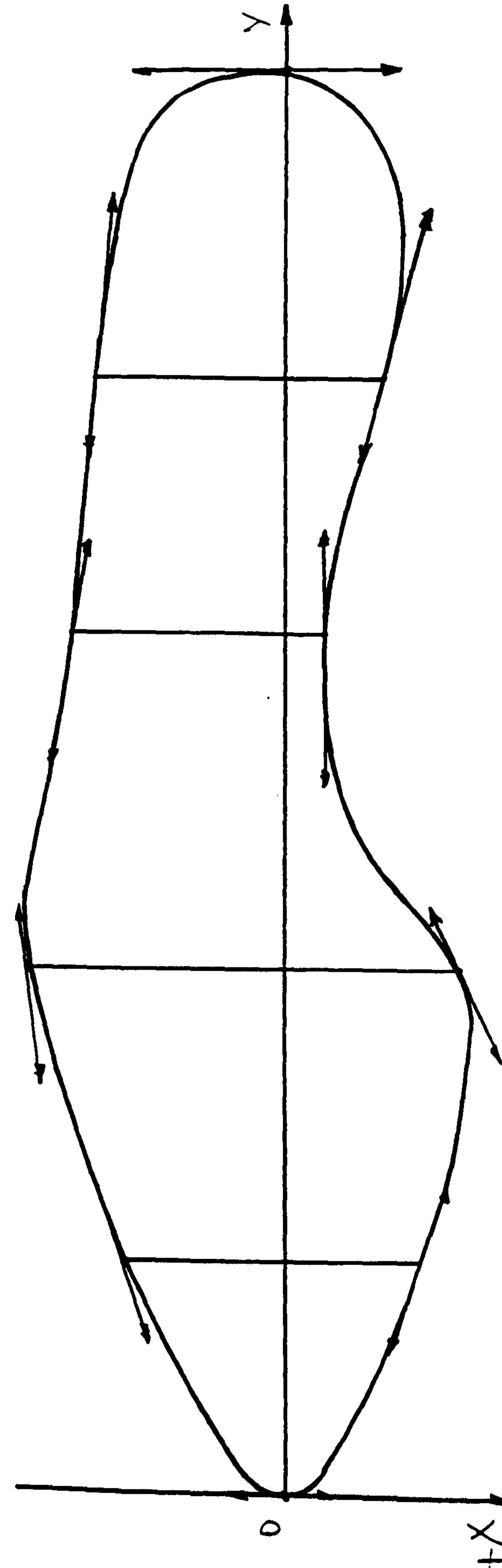


Figure 7.5 The last bottom pattern generating

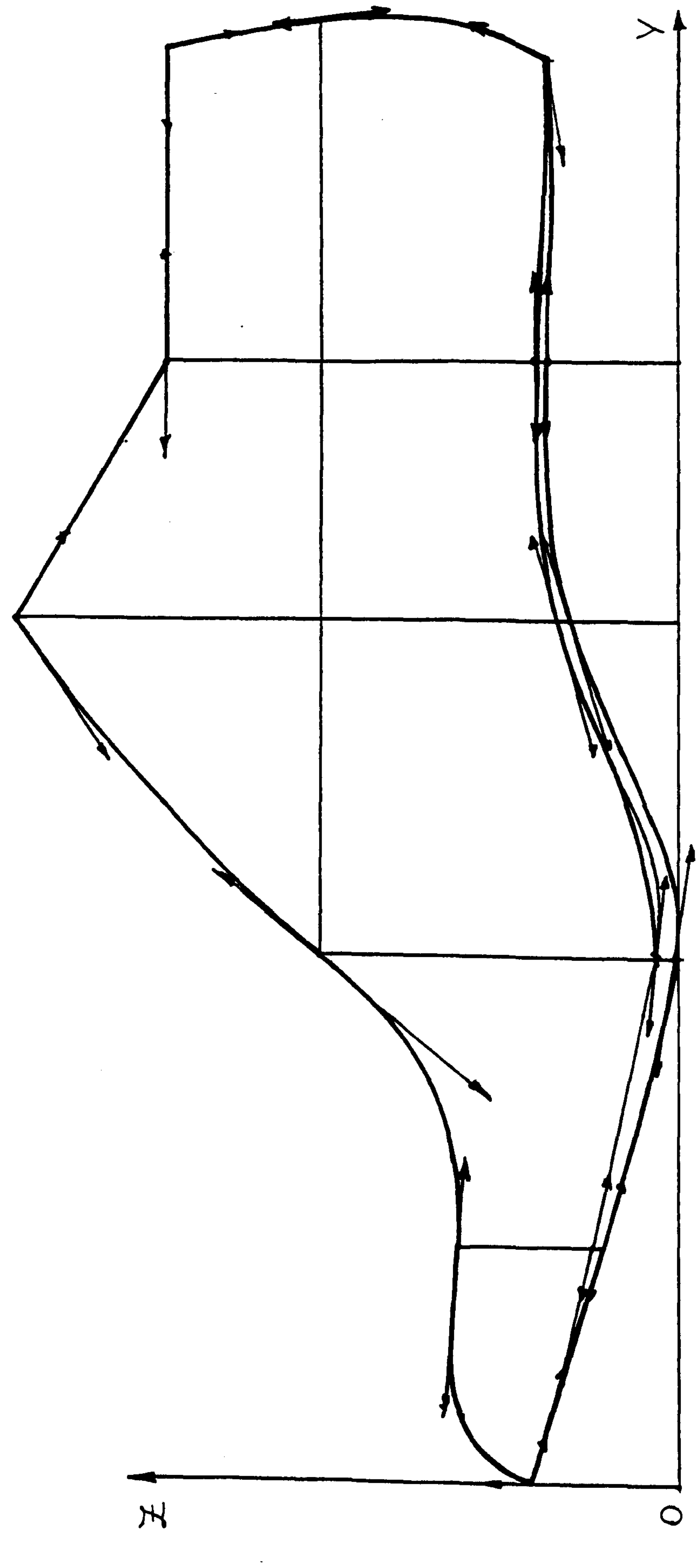


Figure 7.6 The last profile contour generating

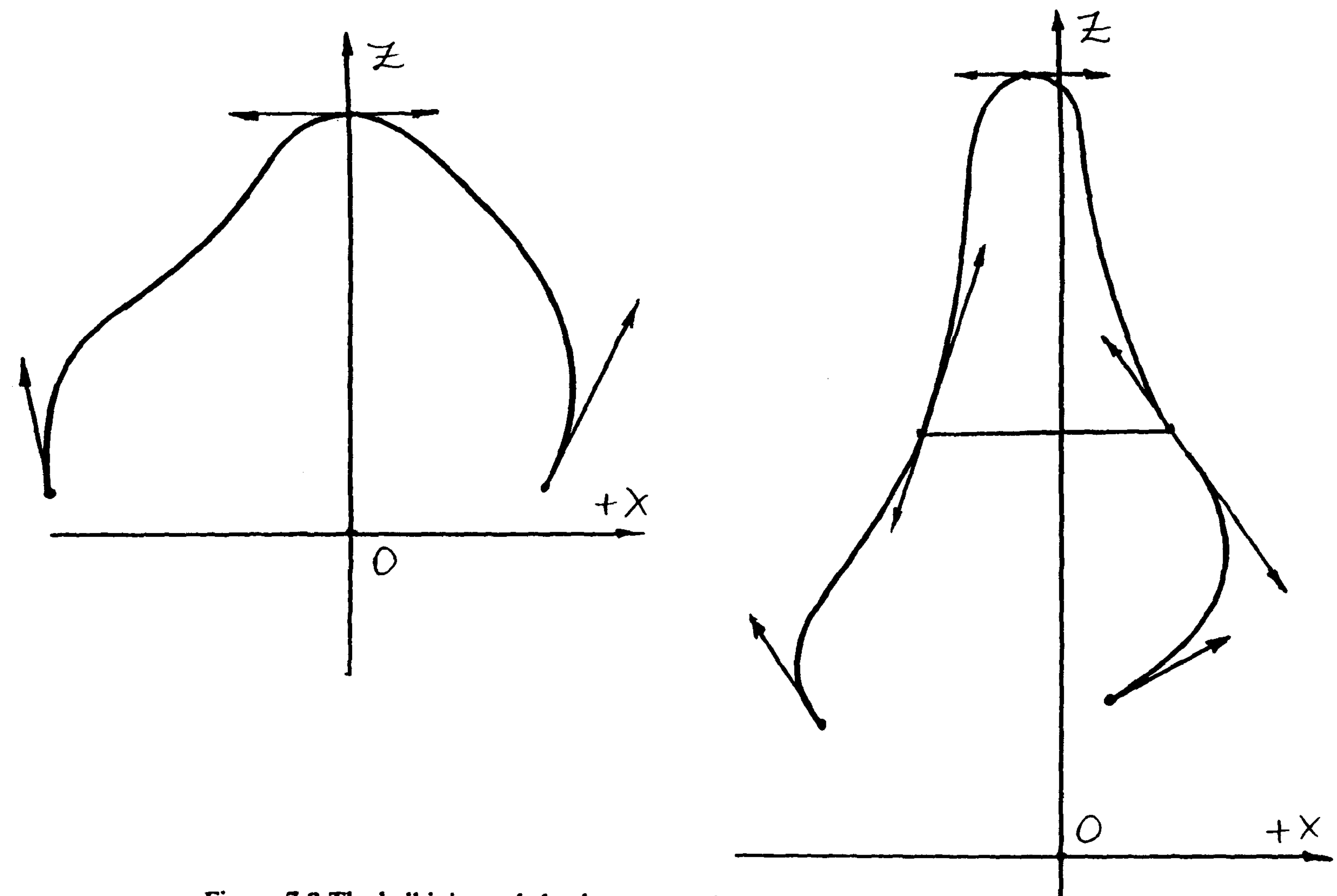


Figure 7.8 The ball joint and shank cross-sections generation

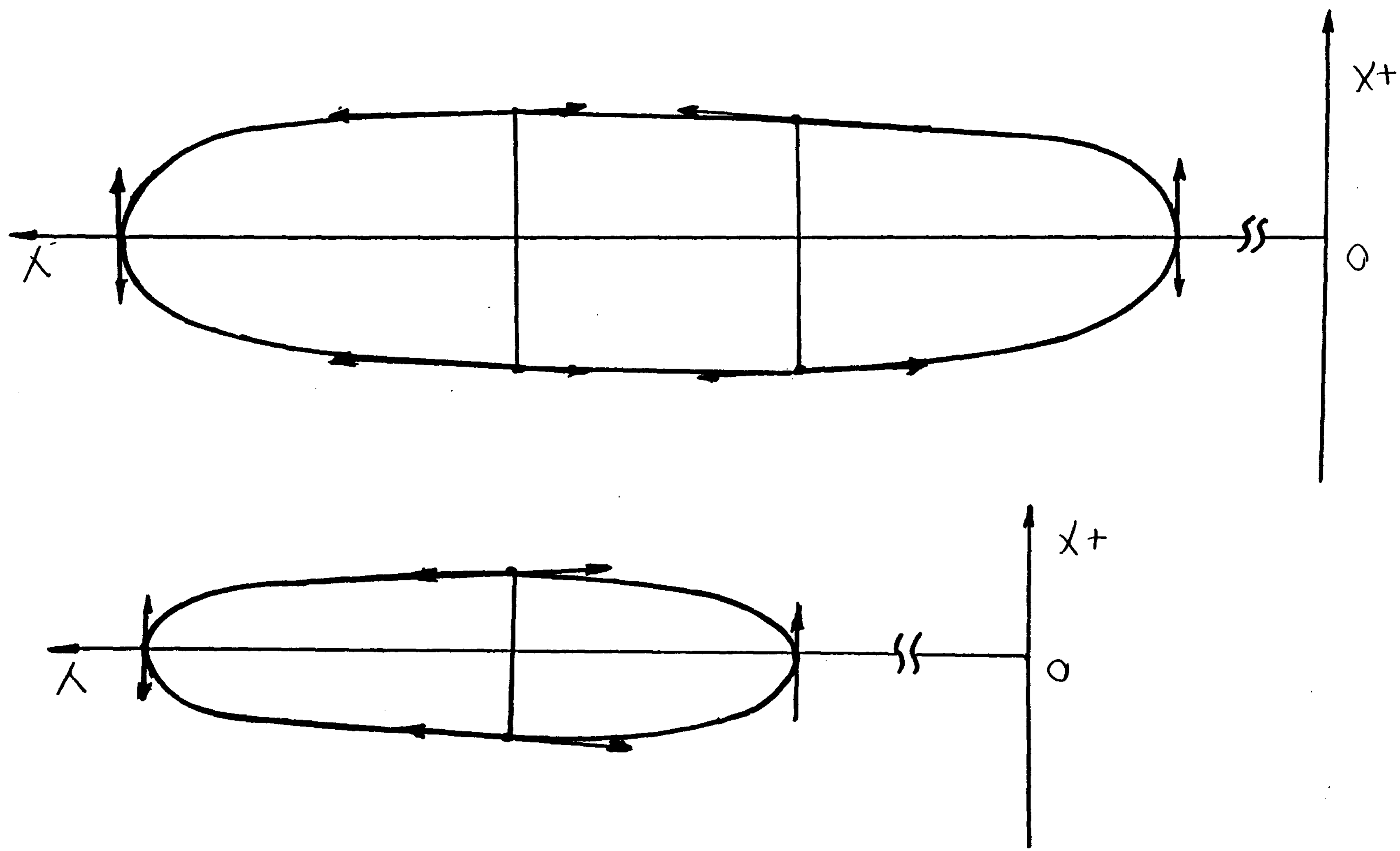


Figure 7.7 The contours of the cone top plane and the waist generation

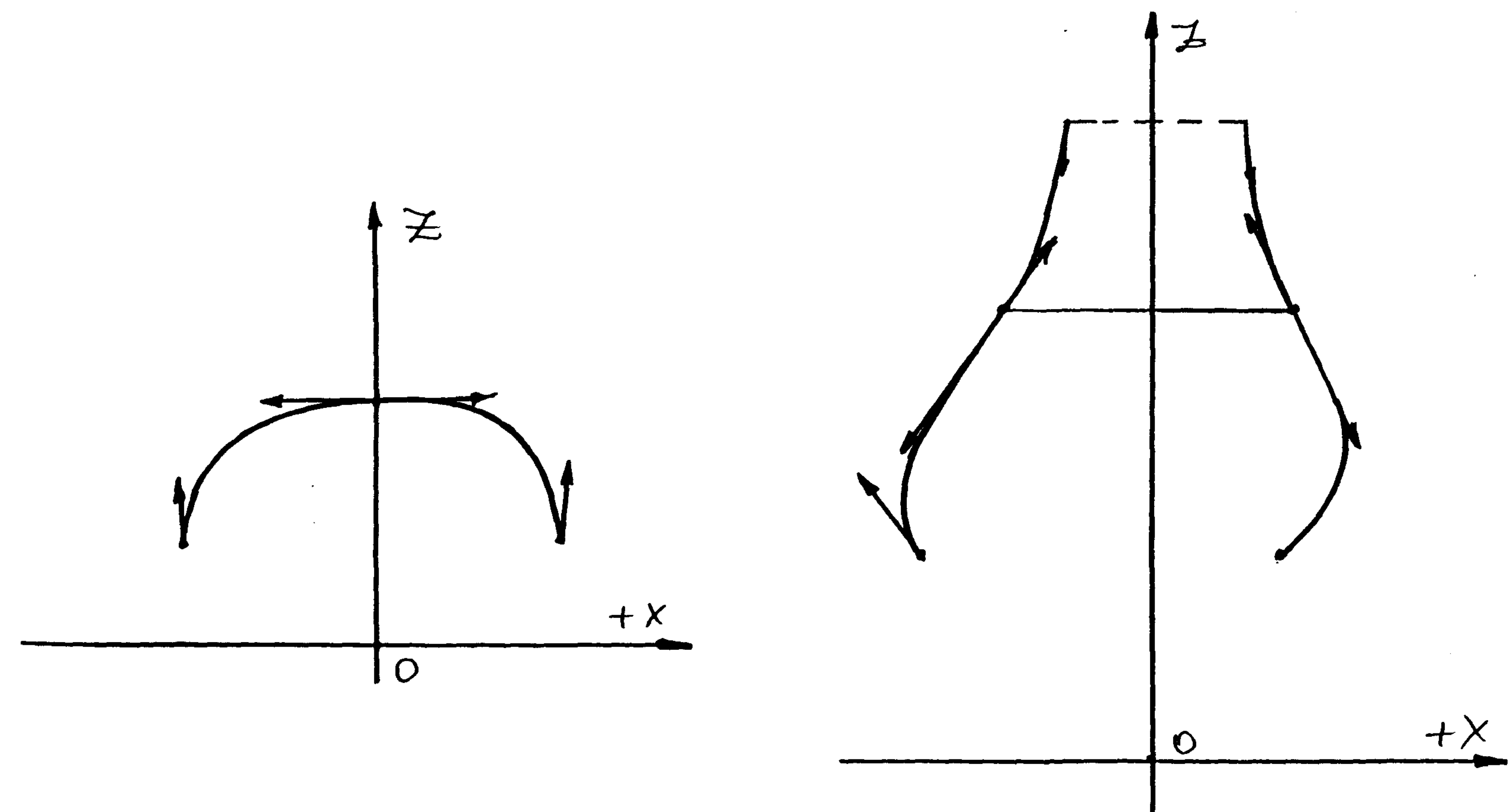


Figure 7.9 The toe and seat cross-sections generation

- shank shape;
- ball joint cross-section shape - the perimeters should be the same, but the higher the heel, the narrower the section in order to prevent the foot slipping ahead forward;
- toes cross-section shape - the same as the above, or alternatevily, alterations are made according to the design style;
- the upper point of the front cone profile in the toe and ball joint sections is moved in the direction of the big toe;
- the length of the front cone profile and the bottom pattern of the lasts (except the shift value) are almost the same for different heel elevations.

The research has revealed the laws shown in Table 7.1.

Modifi-cations	**Parameters changing**		
	Bottom Pattern	**Profile**	**Sections**
Increasing the heel height by 10 mm	Bottom shortening by 0,5 mm; Changing the curvature of the shank part of the contour; Narrowing in sections: ***0,68/0,72L*** by 0,5-0,6 mm; ***0,18L*** - by 0,5 mm;	Shift of the heel curve contour lowers the most forward point; Changing the curvature of the shank part; Reduces the toe spring 1 mm;	Narrowing the seat section – by0,5 mm and the ball joint section – by 0,5-0,6 mm while retaining the perimeter; Narrowing the toe section while retaining the perimeter;
Changes according to fashion trends	Increasing the toe allowance when narrowing the toes of the last;	Change the profile contour;	Change the shape and the perimeter of the toe section; Change the shape of the ball joint section;

Table 7.1 Laws of changing the last form at increasing the heel height

Pursuant with the laws revealed and as the result of the analysis of the last surface modifications by modern CAD/CAM systems (4.2.4) the list of possible global modifications of the surface patches submitted below has been developed in the work. Five of these possible modifications were chosen for further investigation.

The list of possible last surface modifications

1. Changing heel height:

- turning seat-shank part;
- raising back part in parallel to the base plane;
- changing the angle of turning of the toe part;

2. Changing toe spring;

3. Changing curvature of the shank profile;

4. Changing the space situation of the bottom contour;

5. Changing the contour of the seat cross-section;

6. Changing the heel curvature contour;

7. Changing the space situation of the front cone profile;

8. Turning the axis of symmetry of the seat in relation to the bottom axis or the line of the ball joint;

9. Turning the axis of symmetry of the cone top surface in relation to the bottom axis;

10. Turning the line of the ball joint in relation to the bottom axis;

11. Changing the ball girth;

12. Modification of the toe shape in accordance with fashion trends and the functional needs of the footwear;

13. Modifications dependent on technology of footwear assembly;

14. Modifications for orthopaedic purposes.

7.3 Last shape modifications in MicroStation software environments

In order to establish the necessary software for the research, MicroStation software for 3D modelling had to be mastered.

To test the opportunity of the surface controllability and to study the behaviour of the 3D last surface at various manipulations, preliminary experiments on modifying the surface were conducted. For this purpose the following operations of manipulating the last form were carried out:

1) manipulating heel elevation to a certain height taking into account the shank profile shape;

2) manipulating toe spring - turning the toes relative to different axes;

3) narrowing the back part;

4) defining a law for shaping shank profile ;

5) defining the exact position of a front cone profile;

6) shortening the bottom pattern in the seat with respect to the shift value;

7) changing the shapes of certain cross-sections.

The listed procedures are global manipulatings in comparison with the methods of manipulating points and vectors but they also permit manipulation of the separate large elements of the last more exactly and correctly using normal practices shoe designers approaches.

Fig. 7.10, 7.11a and 7.11b illustrate the experiment for defining the optimum turning axis of the toe or back-shank part of the last when changing the heel height. The early research to identify laws for last shaping when changing the heel elevation concerned only defining an angle of turning the back-shank part in relation to the axis passing through the tread point and unified a profile curve in the shank part (FUKIN, 1985).

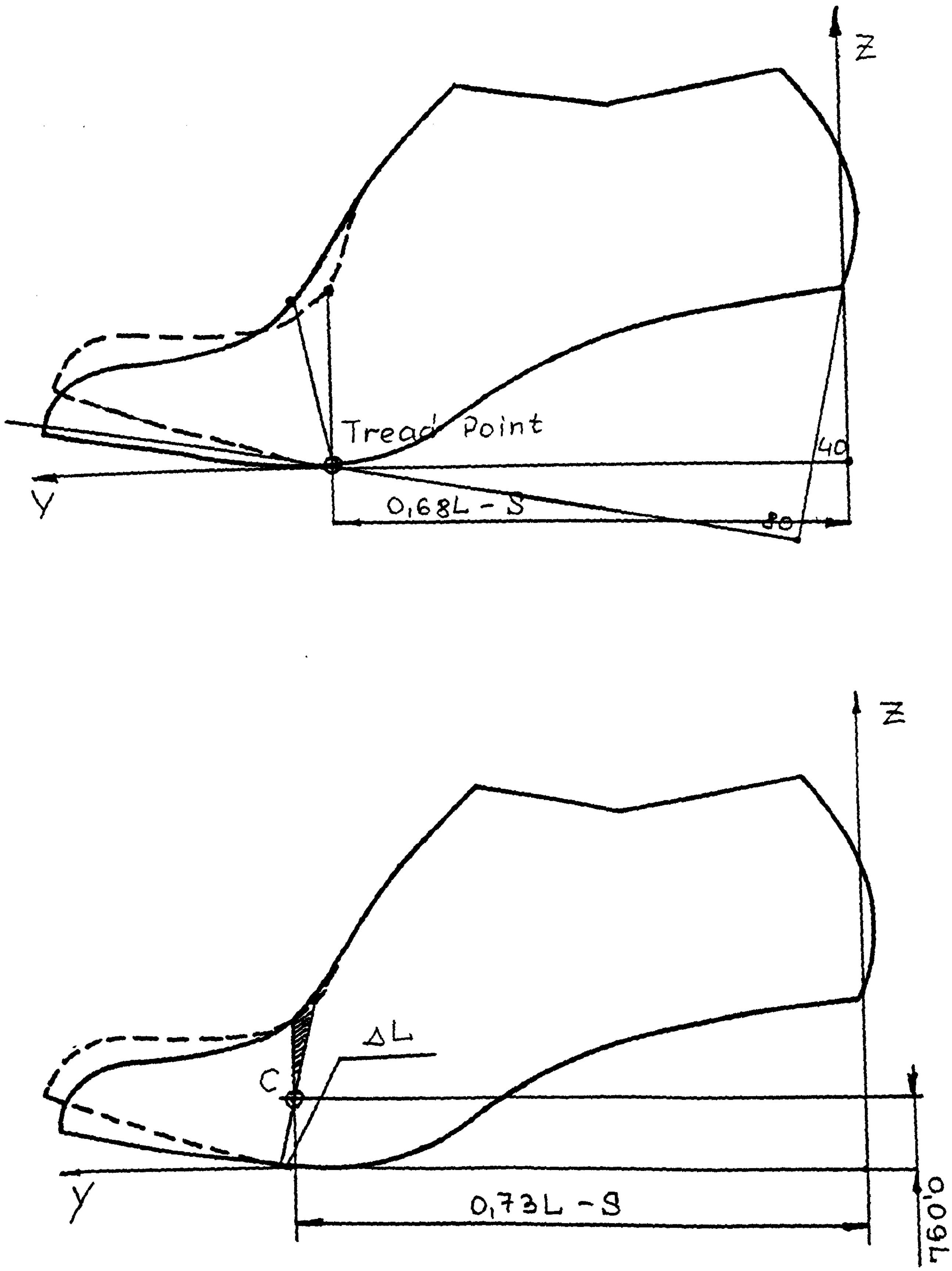


Figure 7.10 Defining the optimum turning axis of the toe or back-shank part of the last

As part of the experiment several variants of situation of turning axis were tested and as the result two of them – axis of standing in the ball joint area (passing through the tread point) and axis passing through the anatomical point (point *C*) of bending the foot (Fig. 7.12) – were chosen for further work. In the first case the result has appeared positive only at small changes of the heel height within the limits of ±10 mm, at greater changing this method did not work well, as the front of the surface had wrinkles, i.e. it has not managed to generate a smooth resulting surface (Fig. 7.13).

In the second case it is possible to change the heel elevation in larger limits and to take into account normal foot functioning in footwear. Fig. 7.14 illustrates the resulting smooth surface generated as the result of turning the toes of the last around the axis going through the point of foot bending (point *C*). However, the length of the bottom pattern was lengthened and the front cone profile was shortened. Nevertheless, the technique is supposed to be very accurate, as the perceived difference is about 1-5 mm; this corresponds to the natural lengthening of the foot when walking or changing the heel elevation. This alteration ought not to be automaticaly taken into account as there is fashion allowance in the toes that is not standardised or could be easily corrected.

Thus it is proposed to use both variants of forepart or back-shank part turning. In this case it does not matter which part (forepart or back-shank part) of the last to turn as both modifications will cause changes in the heel height.

Finding the angle of turning the toe part of the last proceeded from values of inclination angles of the back parts of the lasts with heel heights of 20, 40, 60 and 80 mm, developed by Kochetkova (FUKIN, 1985; KOCHETKOVA et al, 1991). According to Fig. 7.15 the difference of the inclination angles of the back parts of the lasts with the heel heights 40 and 80 mm is *14°*. Thus, within these experiments the toe part of the mathematical model of the last *No 873* was also turned through *14°*. The control of the heel height was then conducted by dropping a perpendicular from the heel point onto the new base plane. The length of the perpendicular was approximately equal to 80 mm, which proved an opportunity for changing the heel height by the method chosen. There were no other means within the software for more accurate procedure of checking the results, i.e. it was impossible to measure the real distances, perimeters or areas of free-shaped objects on a 1:1 scale.

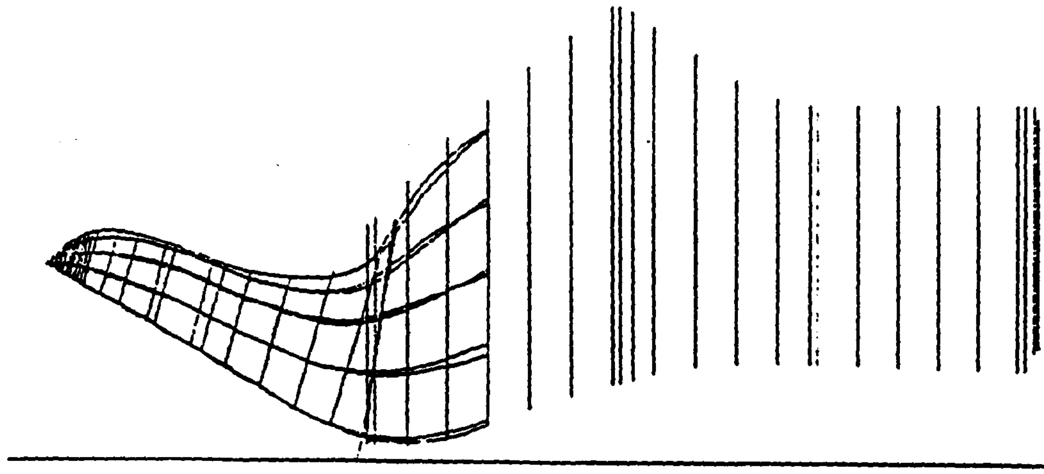


Fig. 7.11a The results of computer experiment of the toe part turning around the tread point

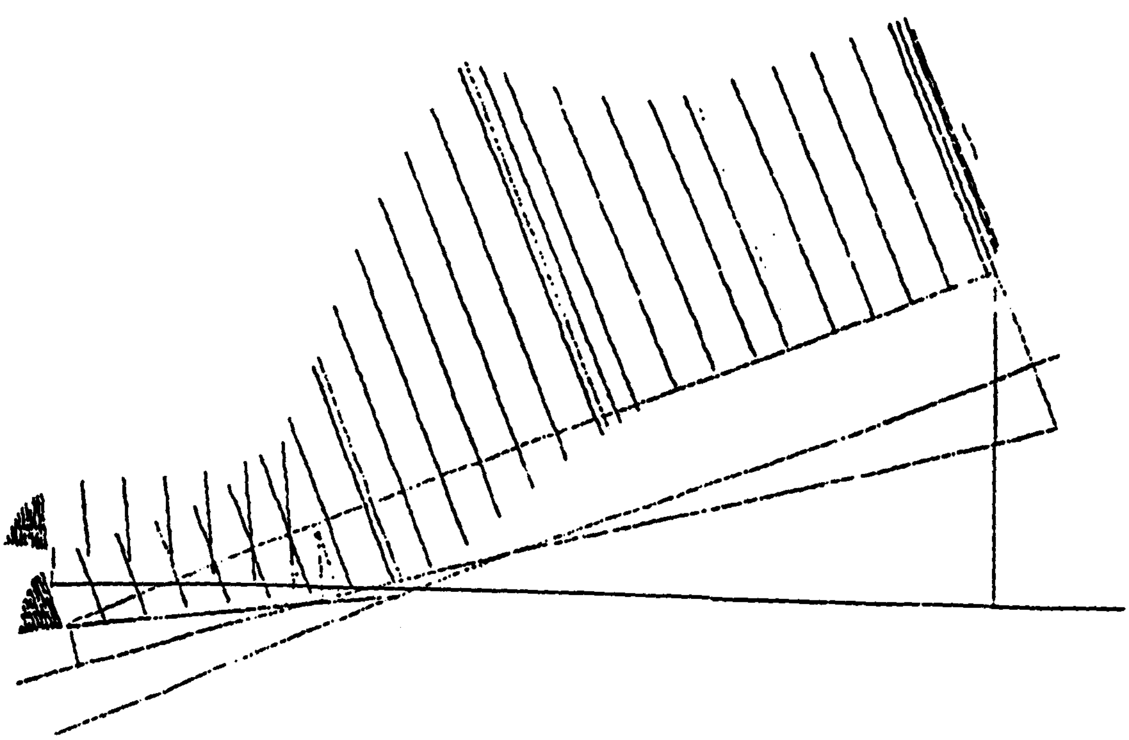


Fig. 7.11b The results of computer experiment of the toe part turning around the foot bending point

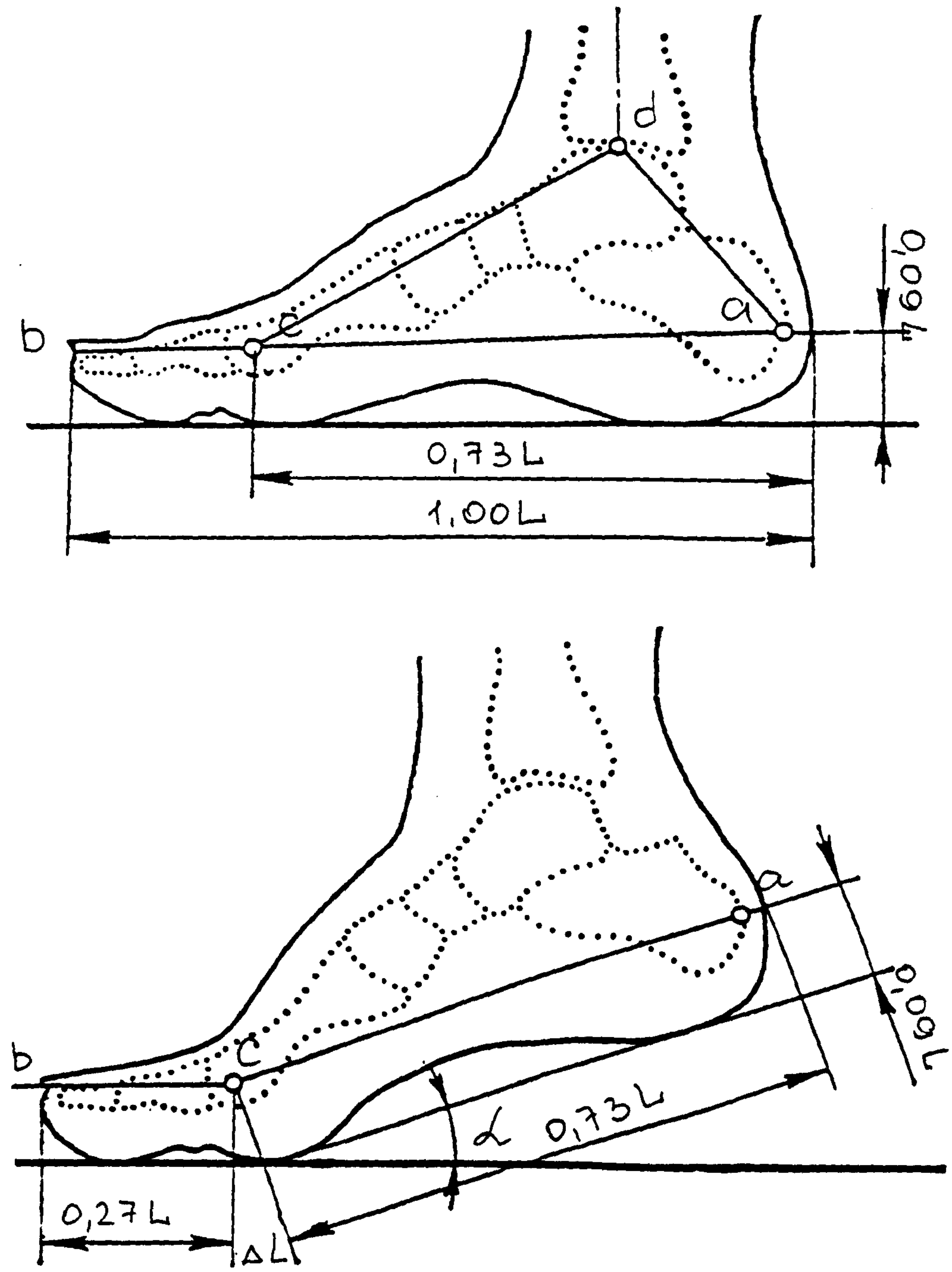


Fig. 7.12 Position of the anatomical point of bending the foot

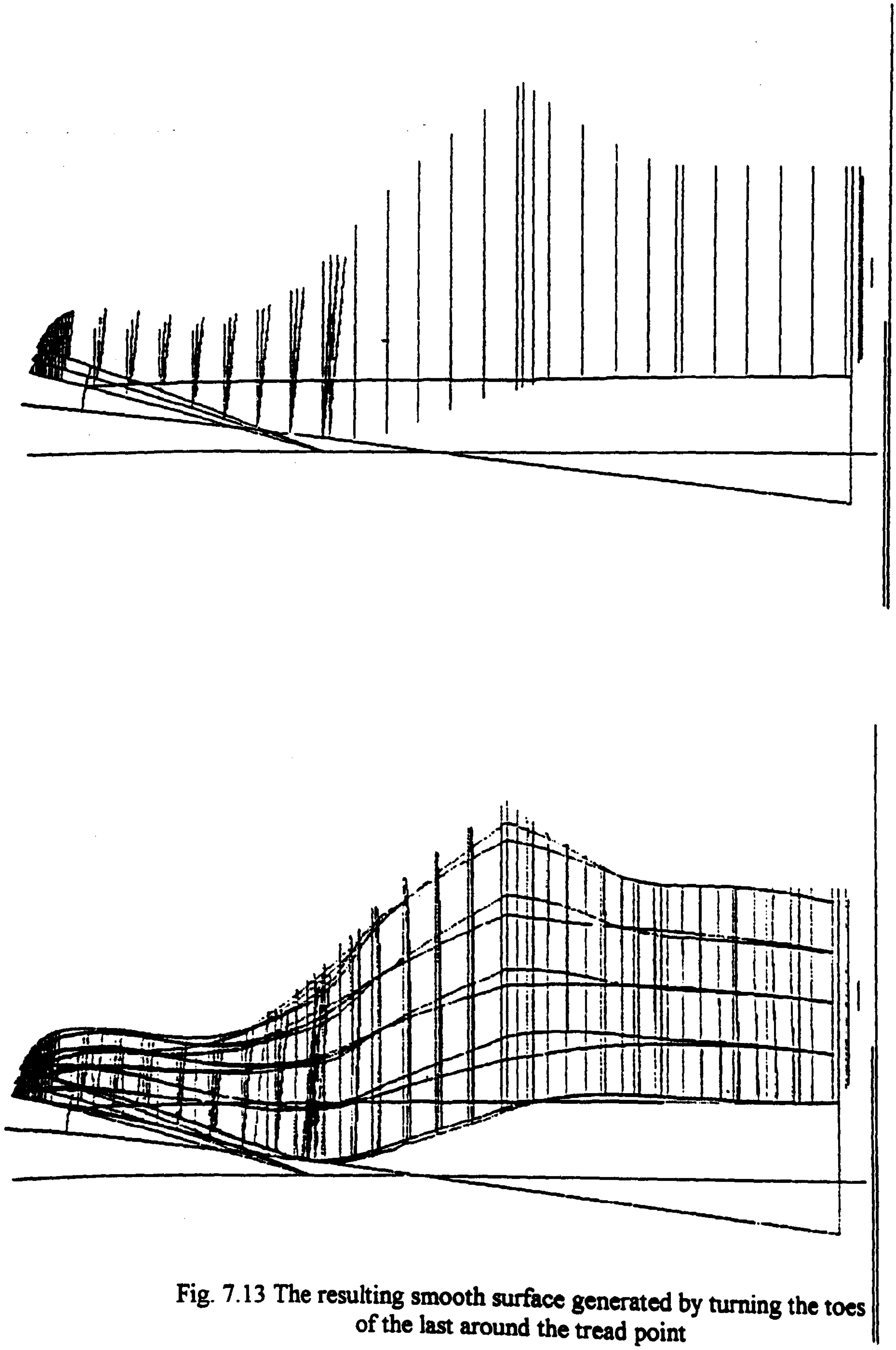


Fig. 7.13 The resulting smooth surface generated by turning the toes of the last around the tread point

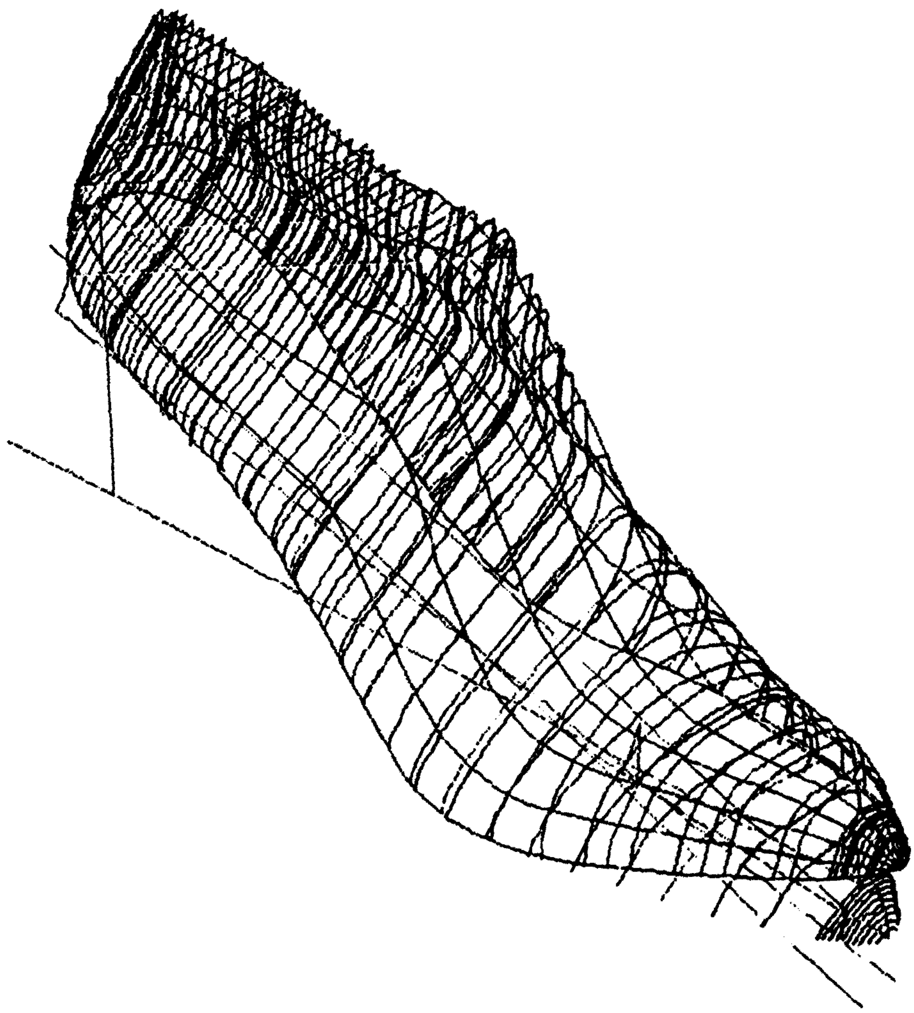


Figure 7.14 The resulting smooth surface generated by turning the toes of the last around the axis going through the foot bending point

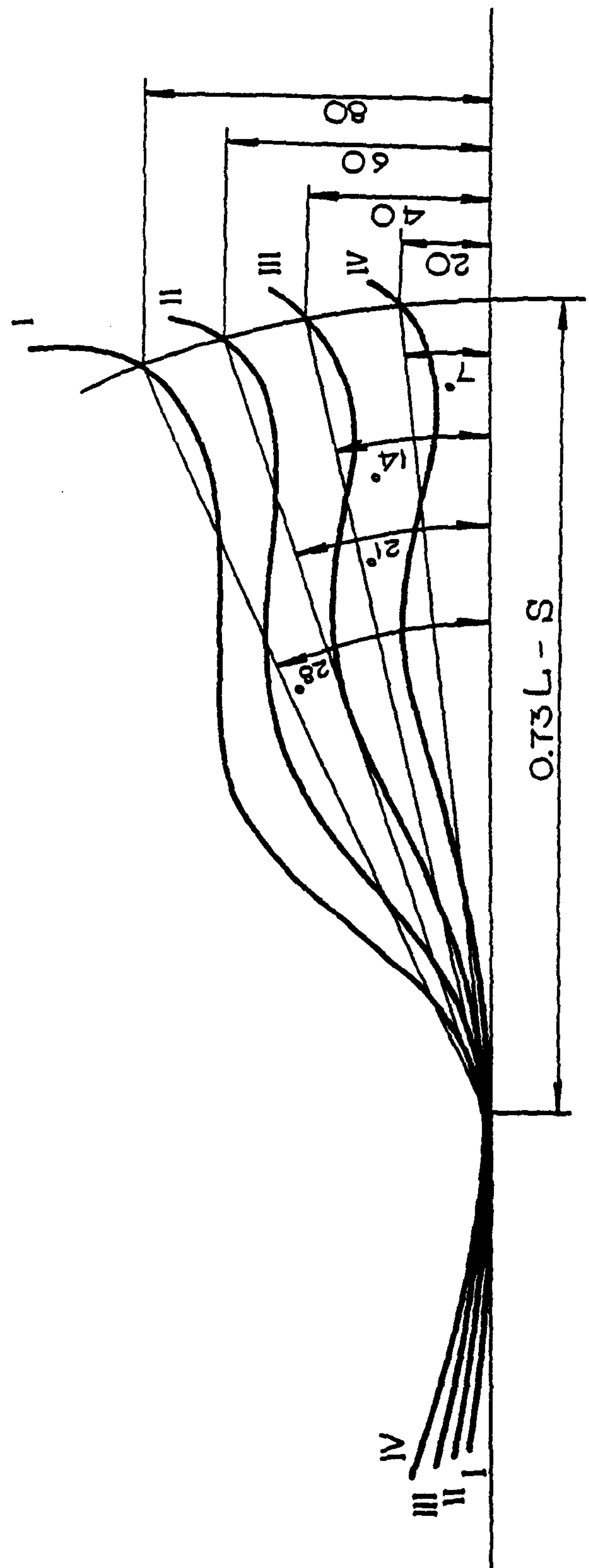


Fig. 7.15 Values of the inclination angles of the back parts of the lasts with the heel heights 20, 40, 60 and 80 mm

Besides, according to the developed list of modifications when increasing the heel elevation it is necessary to simultaneously narrow the ball joint and seat cross-sections of the last.

First of all, it was necessary to define the value and character of narrowing the base seat section. As the analysis of the lasts (Appendix G and Table. 7.1) shows for each 10 mm of increase in the heel height it is necessary to narrow the width of the bottom pattern at the sectio ***0,18L*** by 0,5 mm. As it is clear from Appendix G the consecuential effects of narrowing the bottom dimensions is the need for the back part section to be enlarged to preserve the width of the cone top plane. On the other hand, according to the approach (CHENTSOVA, 1974), it is recommended that the narrowing of the ***0,18L*** section should be carried out by an equidistant grading approach relative to the lateral surface of the last (Fig. 7.16). Such an approach allows us to take into account the narrowing the total back department of the last in accordance with the normal forward displacement of the foot caused by raising the heel height. The research approach is more rational when narrowing the back part section.

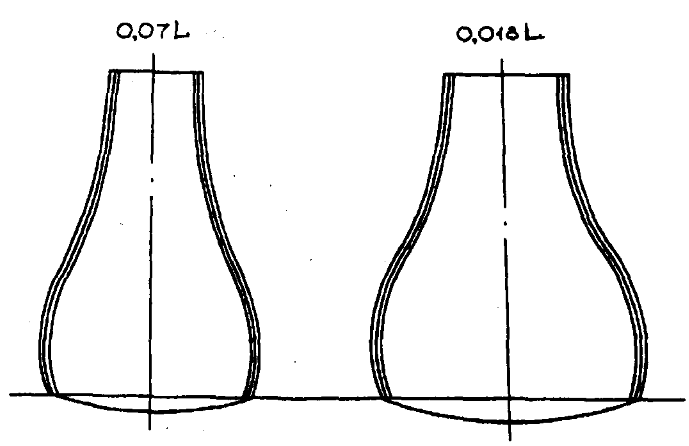


Fig. 7.16 Example of narrowing the last seat section according to the heel height

Within the experiment of increasing the heel height by 40 mm the back part shape was narrowed by 1 mm from inner and outer sides by zoom function (proportional reduction or increase of an object size). However, it proved to be impossible to simultaneously change the form of the ball joint section since at narrowing of the width of the bottom in this section needs to be performed without change in the bottom perimeter. Thus, it is especially important to correctly shape the section since it is the most important in respect to footwear comfort. Thus, the MicroStation software facilities allowed experiments related to narrowing of the back part of the last.

The small number of manipulations examined was caused by the limitations of the MicroStation software. The list below is characteristic of the majority of unspecialised software. According to this, the usage of this software does not seem efficient and to meet the specialist needs of this project specific routins would need to be established.

Disadvantages of MicroStation software

- Time-consuming software as it was not designed for footwear purposes (to fulfil certain operations it requires the use of a number of options);
- Labour intensive (to set croos-sections it requires the input co-ordinates of each point);
- Using arch-interpolation (the only available) does not allow to create a realistic surface;
- B-spline surface (the only available) requires the use of different mathematical tools for the various design steps (initial data were translated from the module used to of generate the mathematical model based upon Bezier curves);
- It is impossible to create a whole smooth surface, so it requires the creation of separate parts followed by stitching them together (Fig. 7.14);
- After each modification of the surface the whole surface needs to be generated again;
- It is very difficult to create the surface in the toe and back part regions as quadrangular patches degenerate into triangular forms;
- There are discrepancies in the surface when setting surplus data; however, if less data then the minimum need, the surface becomes less realistic;
- It provides either manipulations of each vertex of the surface, or general manipulations like enlarging or moving in parallel with simultaneous enlarging or reducing, this makes it very difficult to alter the shape of cross-sections without changing perimeters (Fig. 7.16);

As a result of the experiment at work it is possible to draw the following conclusions:

- At all stages of designing it is recommended to use the uniform mathematical approach;
- It is inconvenient to use B-splines for the purpose of last designing without starting form a sample last;
- It is necessary to use specially written software.

However, there were obtained preliminary results o ormanipulating the last form by changing the heel height by turning the toe part around the point C with simultaneous narrowing the back department of the last.

7.4 Specific software for experimental research

In order to conduct the experiment of generating a mathematical model of the last and further experiments for manipulating global sites of the last surface, special software was developed using "Turbo C" (GORDEYEVA and GOROCH, 1998).

To develop the program LAST.EXE for generation of last mathematical model the following were taken into account:

1. The need to allow visualisation of the last surface skeleton in projections so enabling the accuracy of reproduction of the contours to be monitored;
2. To allow control of smooth stitching of the elementary patches of the last surface;
3. To supply an opportunity for complex evaluation of the aesthetic appearance of the last ;
4. To allow control of the whole surface image at intermediate transverse-vertical sections.

The software uses the data file developed in 6.4. The procedures of skeleton co-ordination executed in the program to account for the smooth surface are also described in 6.4.

Fig. 7.17 illustrates the algorithm used in the LAST.EXE routine. The visualisation of the results of modelling begin in blocks 3 and 4. Thus, on screen isometric projection

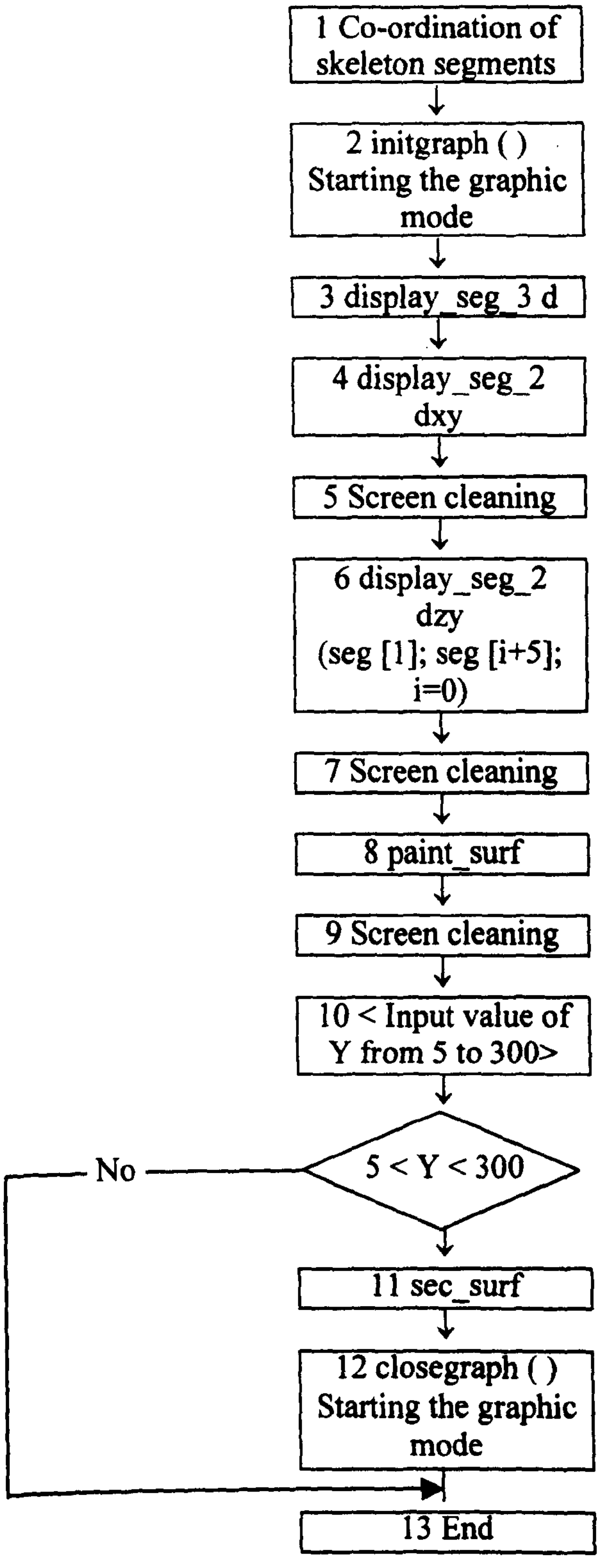


Fig. 7.17 LAST.EXE software algorithm

(block 3) and a projection of the skeleton onto ***YOZ*** plane (block 4) (Fig. 7.18) are simultaneously displayed. By use of an appropriate screen scale the given projections monitoring of the accuracy of description for transverse-vertical skeleton section

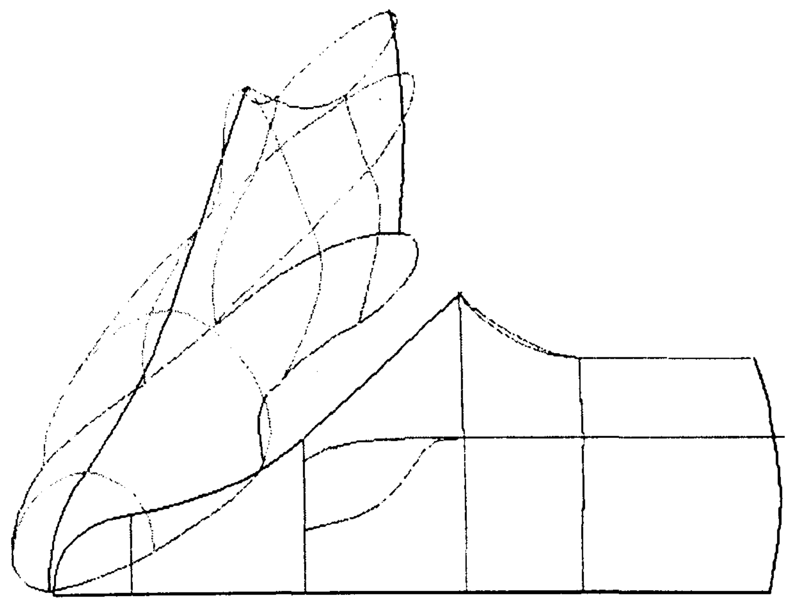


Fig. 7.18 Presentation of isometric projection and a projection

of the skeleton onto YOZ plane

contours, profile contour and projections of the feather line onto the ***YOZ*** plane. In block 6 visualisation of projection of the feather line contour on ***XOY*** plane is processed, this permits the monitoring of the bottom contour as carried out in traditional techniques of last modelling.

Evaluation of smoothness of elementary surface patches stitching is carried out by a course of parametrical lines (Fig. 7.19). In block 8 the calculation of the surface and illustration using parametrical lines is fulfilled using an equal step of V parameter. For evaluation of the aesthetic appearance of the last the parametrical surface is realised in isometric projections. Thus, the right bottom segment is firstly painted over, and then – the left-hand bottom segment for each of the zones, beginning from the back part, then in the same sequence the top segments of the surface are painted over. The patch ***OOt*** for different segments is gone around in different directions. For establishing a correct sequence for the curve segments, a procedure of turning a segment <rev_seg> was developed.

For whole surface control on intermediate transverse-vertical sections in the block 11, a section calculation with co-ordinate on ***Y*** set in the block 9, is executed. The contour of

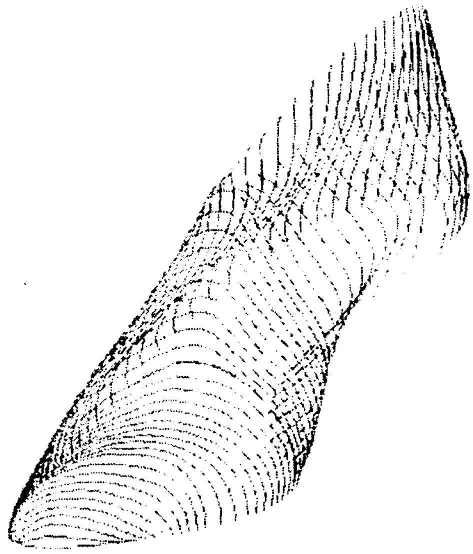


Fig. 7.19 Presentation of the last surface by parametrical lines

the section is displayed on screen in a discrete-digital mode. The procedure <sec_surf> (block 11) executes going around the surface similarly to the sequence used in block 7 to search for points with a given *Y* co-ordinate.

There was developed a modification of the program LAST.EXE - program PRINT_SEC.EXE, performs data listing, which for section contours as a table of points in the Cartesian co-ordinate system.

To realise experiments for manipulating global patches of the last surface two modifications of the program LAST.EXE – 2DMODKOM.EXE and 3DMODKOM.EXE were developed.

The program 2DMODKOM.EXE except functions stipulated by the program LAST.EXE contains procedures of global manipulating the last surface by turning the last forepart around the tread point and raising the last back part department parallel to the base plane. The program 3DMODKOM.EXE differs from the previous version by having additional procedures for global manipulations of the last front cone profile.

The programs LAST.EXE and 2DMODKOM.EXE use data files (last.ini and 2dlst.ini respectively) where the last is perceived as a last with a flat bottom (Appendix F) and the data file 3dlst.ini used in the program 3 DMODKOM.EXE yields a construction of the last skeleton with 3D bottom (Appendix H).

For approbation of the procedure of generating a unified curve in the shank part of the last profile the program GELENOK.EXE using data file "sec" was developed.

7.5 Methodology of manipulation of the last surface global parts

To develop a method of manipulating a shoe last shape with the purpose of designing a new style, an experiment was conducted for forming the surface of a shoe last by manipulating its global patches (GORDEYEVA, 1997; GORDEYEVA and GOROCH, 1998).

Thus, investigation of behaviour of the volumetric last surface for various manipulations were conducted. With this purpose, special software, described above, was developed. For this ladies lasts for court shoes of models *No 873* and *No 875* (made on Italian prototypes at "Alba" factory that produced well-fitting ladies court shoes) were chosen. The experiment consisted of automatically modifying the shape of last *No 873* with the heel height 40 mm to create a last with the heel height 80 mm, and comparing the CAD generated sections form the mathematical model of the last with sections taken from last *No 875*. The list of global manipulatings included changing heel height, defining exact position of the front cone profile with a characteristic slight inward turn and generating a unified curve in the shank area of the last profile between the sections ***0,18L*** and ***0,73L***.

7.5.1 Choosing lasts for the research

To make a conclusion about adequacy of the results generated during the experiment it is necessary to choose lasts, which fulfill the following requirements:

- Compared lasts should be of very similar style;

• Compared lasts should have a significant difference in heel height from (20 up to 40 mm) to enable the differences between them to be clearly characterised;

• It was desirable to investigate lasts for ladies court shoes as the modelling of these types of footwear have higher demands from the point of view of fit, aesthetic appearance and close fixing of footwear on a foot with the absence of special fastening;

• Researched lasts should work well at manufacture and conform to all requirements presented to the rational form of footwear.

Based upon the above requirements the lasts submitted in the Table 7.2 were chosen to conduct the research.

Classification attributes (according to Russian State Standard for lasts)	Last of model No 873	Last of model No 875
System of measurement	Continental Sizing and Fitting	Continental Sizing and Fitting
Last number	385	385
Last fit	4	4
Last group	8	8
Footwear type	Shoes	Shoes
Last type	Production	Production
Construction	One-piece	One-piece
Material	Polyethylene	Polyethylene
Made by	Joint-Stock Russian-Italian company "Alba"	Joint-Stock Russian-Italian company "Alba"
Heel elevation, mm	40	80
Measurements		
Last insole length, mm	265	270
Girth in sections, mm:		
0,68/0,72L	230	230
0,55L	240	240
Bottom width in section *0,18L*	55.0	53.0
Bottom width in section *0,68/0,72L*	77.5	74.5

Table 7.2 Choice of lasts for research

Once chosen lasts of the two models were digitised (7.1). Tabulated measurement data of the last *No 875* are indicated in Appendix I. Once constructed and corrected the last transverse-vertical sections were drawn on a transparent material for convenience of their visual comparison with the same sections of numerical models on-screen. Fig. 7.20 and 7.21 illustrate the comparison of initial basic cross-sections of the two lasts to demonstrate the difference of their shape before modifying last *No 873*. The

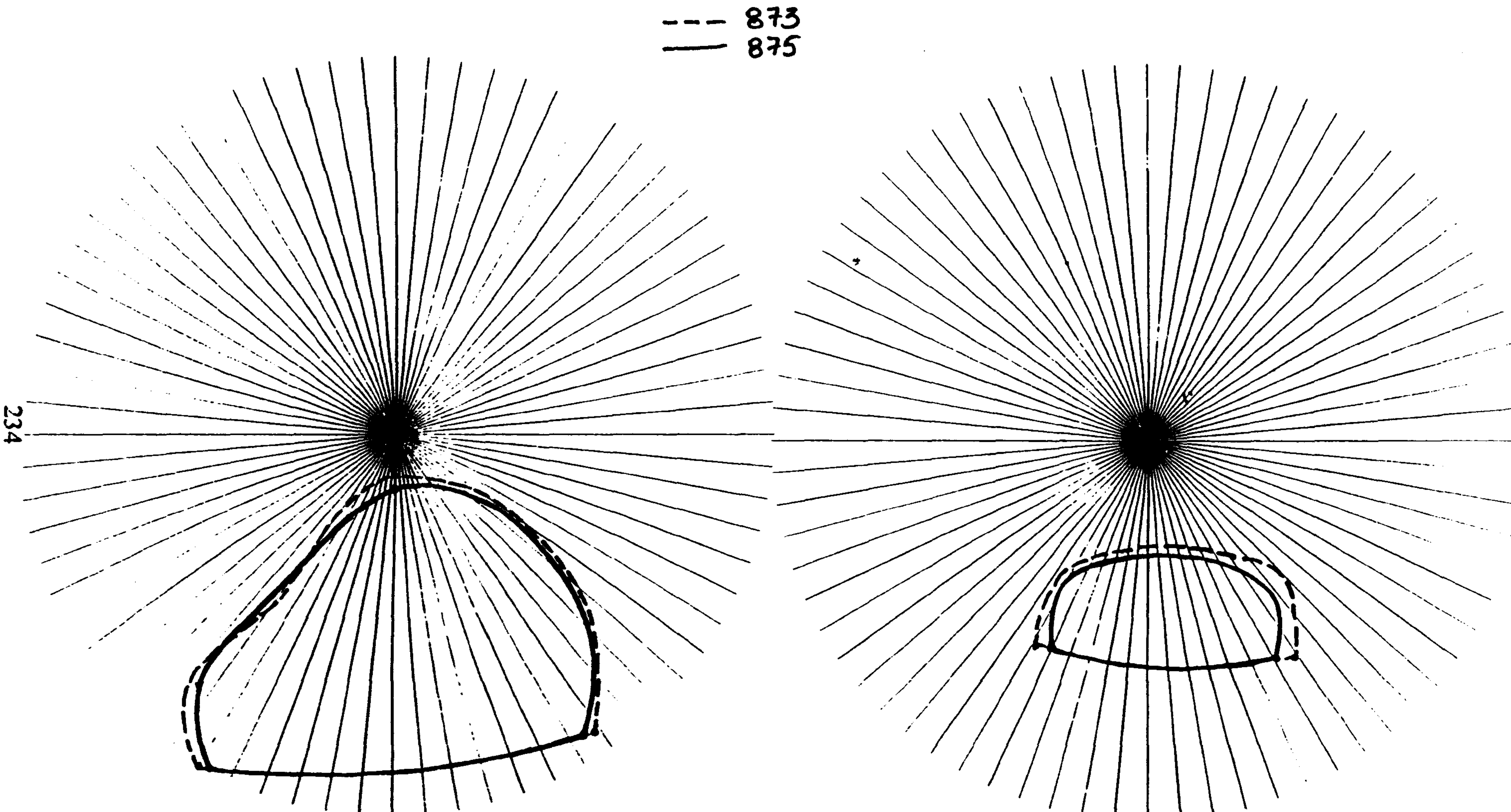


Figure 7.20 Comparison of the sections "Toes" and "Ball Joint" of the lasts *No 873* and *No 875*

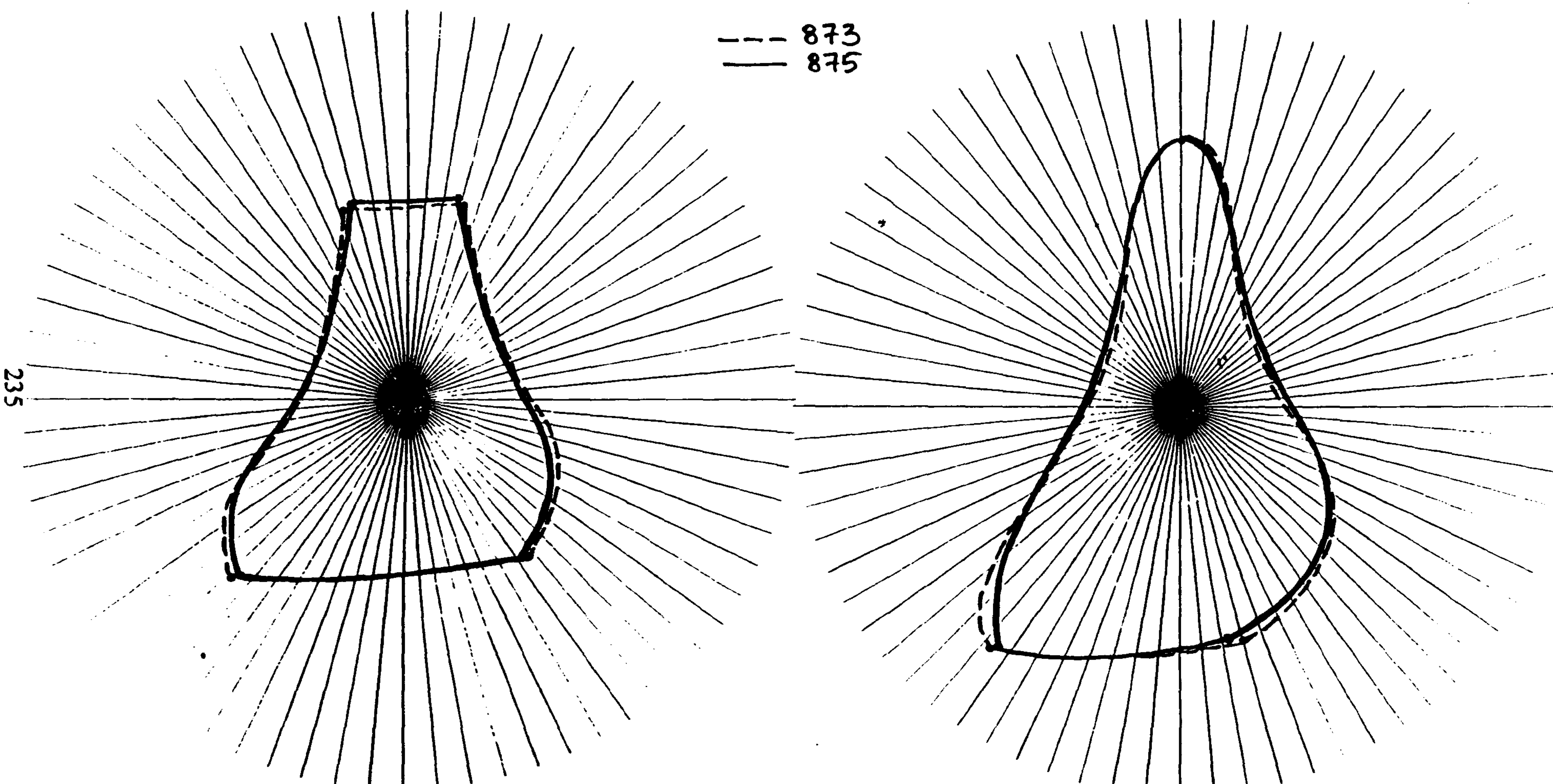


Figure 7.21 Comparison of the sections "Shank" and "Seat" of the lasts *No 873* and *No 875*

difference is in the limits necessitated by the difference in heel heights of the two lasts as defined by law (7.2).

7.5.2 Algorithm of manipulating heel height

In order to conduct intermediate experiment of changing the heel height the data file last.ini containing co-ordinates of basic points and vector derivatives of skeleton sections of the last *No 873* has been changed that enabled to set any value of an angle of turning the last toes and the value of the uprising of the back part department of the last parallel to the base plane (file 2dlst.ini for the program 2DMODIF.EXE).

As was mentioned above the comparison analysis of the shapes of the real lasts for court shoes with various heel elevation revealed the shape alterations including the dependence of heel elevation and toe spring (Fig. 7.15). The table below (Table. 7.3) reflects the relation between the angle of turning of the toes of the lasts and their heel elevation as developed by Klutchnikova (KOCHETKOVA et al, 1991).

Heel elevation, mm	Angle of turning back-shank part of the last, °	Angle of turning forepart of the last, °	Angle of turning forepart of the last, radian
20	7°	9°	0,158
40	14°	7°	0,123
60	21°	5°	0,088
80	28°	3°	0,053

Table 7.3 The relation between angle of turning the toes of the lasts and their heel heights

Fig. 7.22 illustrates intermediate experimentation of raising the back part department of the last for model *No 873*, having a heel elevation of 40 mm, in parallel to the base plane for 40 mm with the purpose of creating a new last shape with the total heel height 80 mm.

In order to check the results of all manipulation experiments, intermediate cross-sections of the two lasts for each particular zone of the last surface were chosen. Those sections were chosen because the basic sections have not been modified during the manipulations (except the manipulation of shaping the cone top plane) and therefore have not been changed. Fig. 2.23 and 2.24 illustrate the comparison of cross-sections of

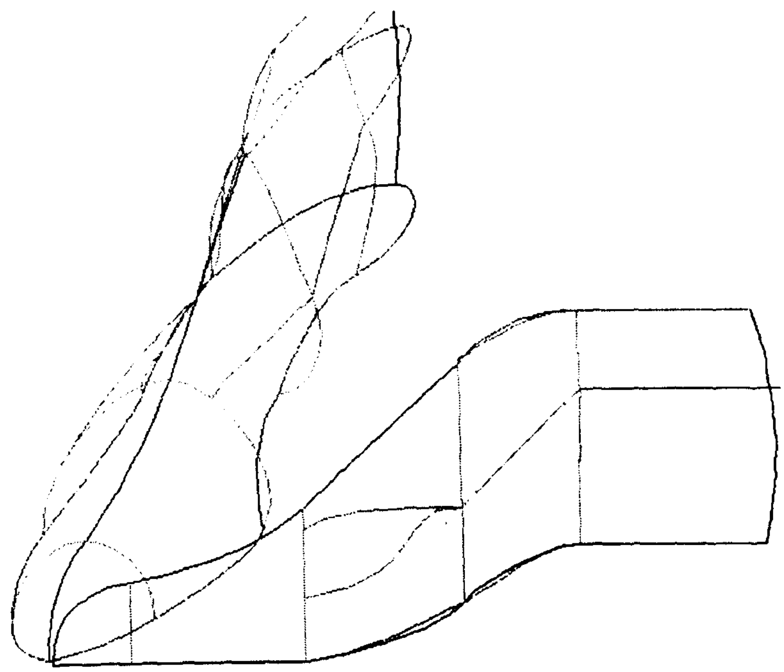


Fig. 7.22 Uprizing the back part department of the last in parallel to the basic plane

the two lasts belonging to the seat and shank (Fig. 2.23) and the ball joint and toes zones (Fig. 2.24) respectively.

After changing the heel height of the last for 40 mm heel height, co-ordinates of cross-sections of a new computer generated last with a prospective heel height of 80 mm were calculated and the images were displayed in a discrete-digital mode (Fig. 7.25). The sections were compared with appropriate sections of the last of model *No 875* with the heel height 80 mm. Results of the comparative evaluation (Fig. 2.26 and 2.27) have shown inadmissible distortion of the last form observed in the case of uprising the seat department for 40 mm that does not meet the requirements of rational designing of the internal shape of footwear. The sections of toes and seat zones have not been changed, but the sections of shank and ball joint areas have been significantly lengthened. It is possible to assume that it is explained by the large difference between the initial and derived heel heights. Further experiments proved that, with use of the given manipulations, it is possible to change initial height of the heel within small limits (about ±10 mm).

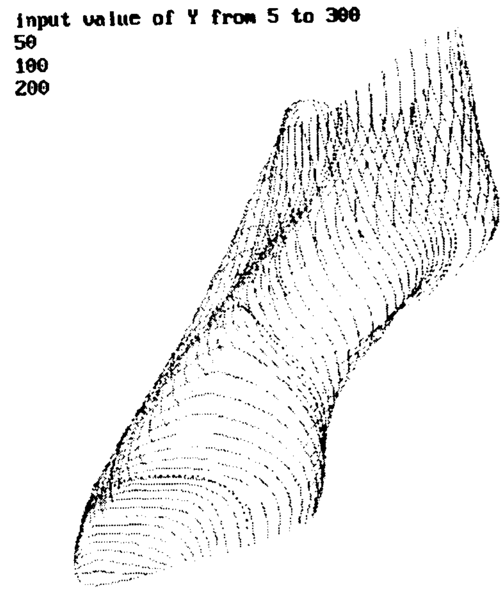


Fig. 7.25 Presentation of the last surface by parametrical lines with cross-sections displayed in a discrete-digital mode

The next intermediate experiment, with the use of the program 2DMODIF.EXE, consisted of turning the back-shank (forepart) part of the last *No 873* around the axis passing through the tread point (Fig. 7.28).

After turning the back-shank part of the last by ***14°*** around the specified axis, co-ordinates of cross-sections of a new last mathematical model with prospective heel height of 80 mm calculated and their images were displayed in a discrete-digital mode. The sections were compared with appropriate sections of the last of model *No 875* with the heel height 80 mm. Results of the comparative evaluation (there is a concurrence of the appropriate sections with the accuracy of 1-2 mm) permit a preliminary conclusion about opportunity of changing the heel height by this procedure. However, a rather large error (about 1-2 mm when the allowable error is up to 0,5 mm) means that it should limit changing the heel height by turning the back-shank part of the last within the limits of ± *10-15°*.

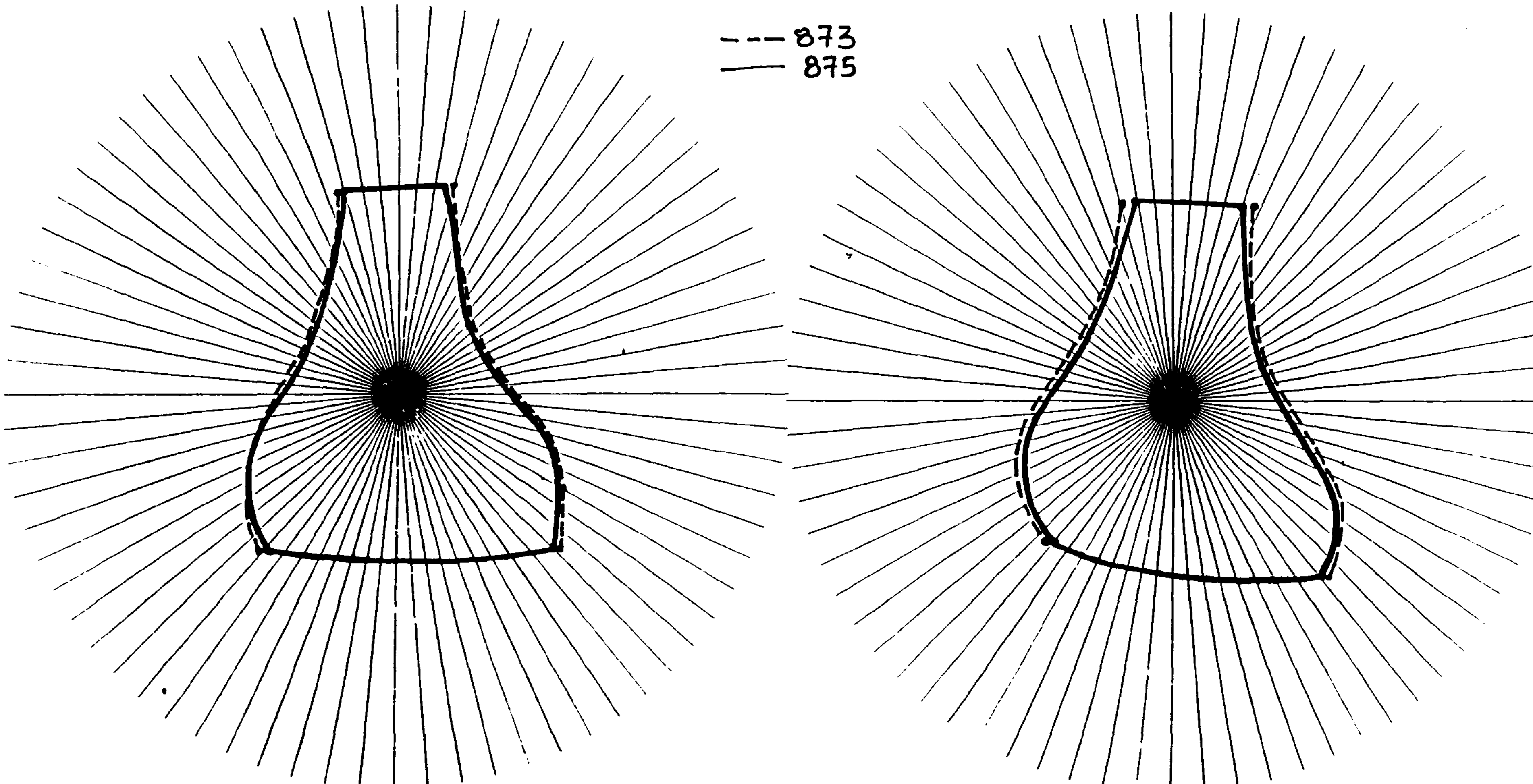


Figure 7.23 Comparison of the lasts sections belonging to seat and shank zones

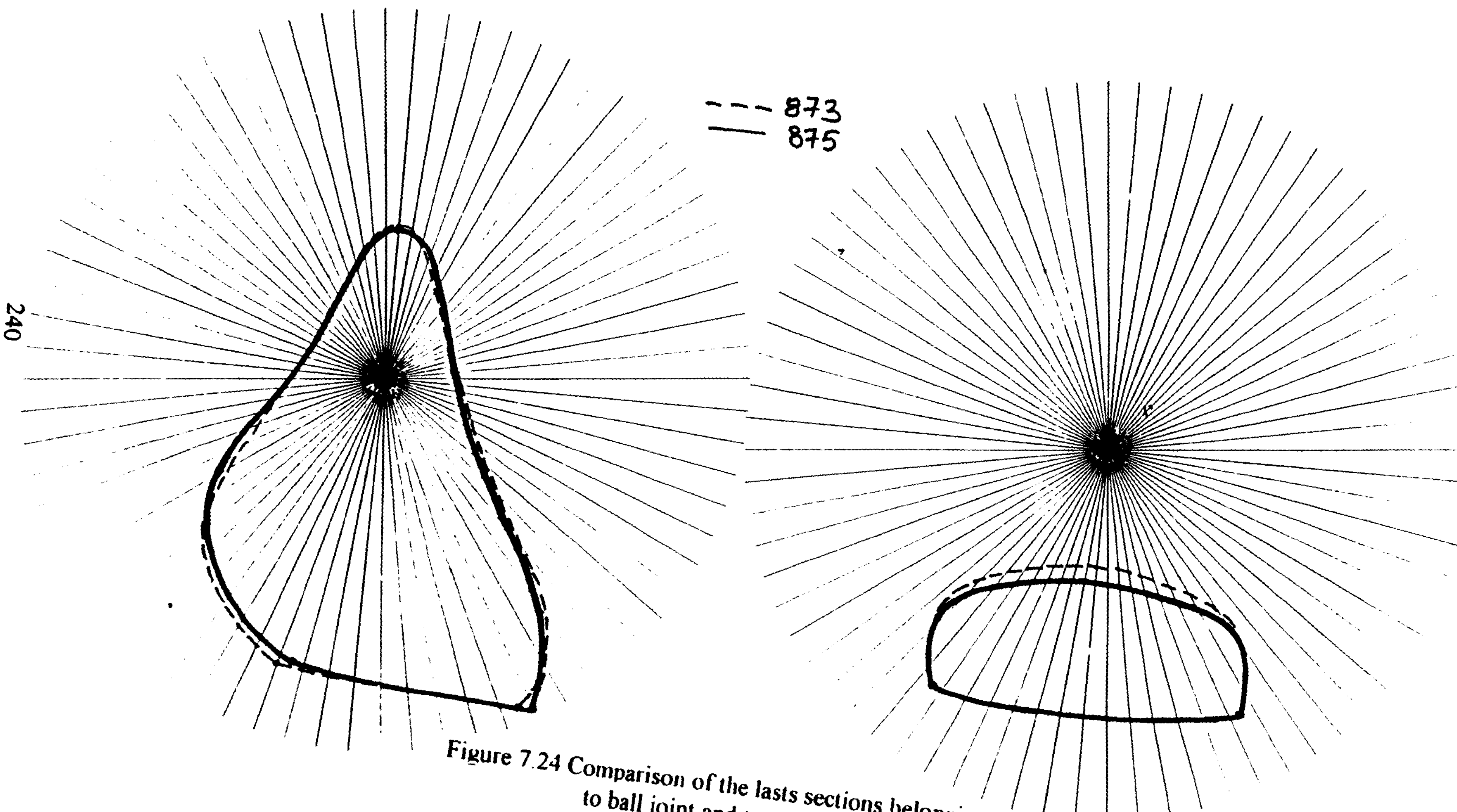


Figure 7.24 Comparison of the lasts sections belonging to ball joint and toes zones

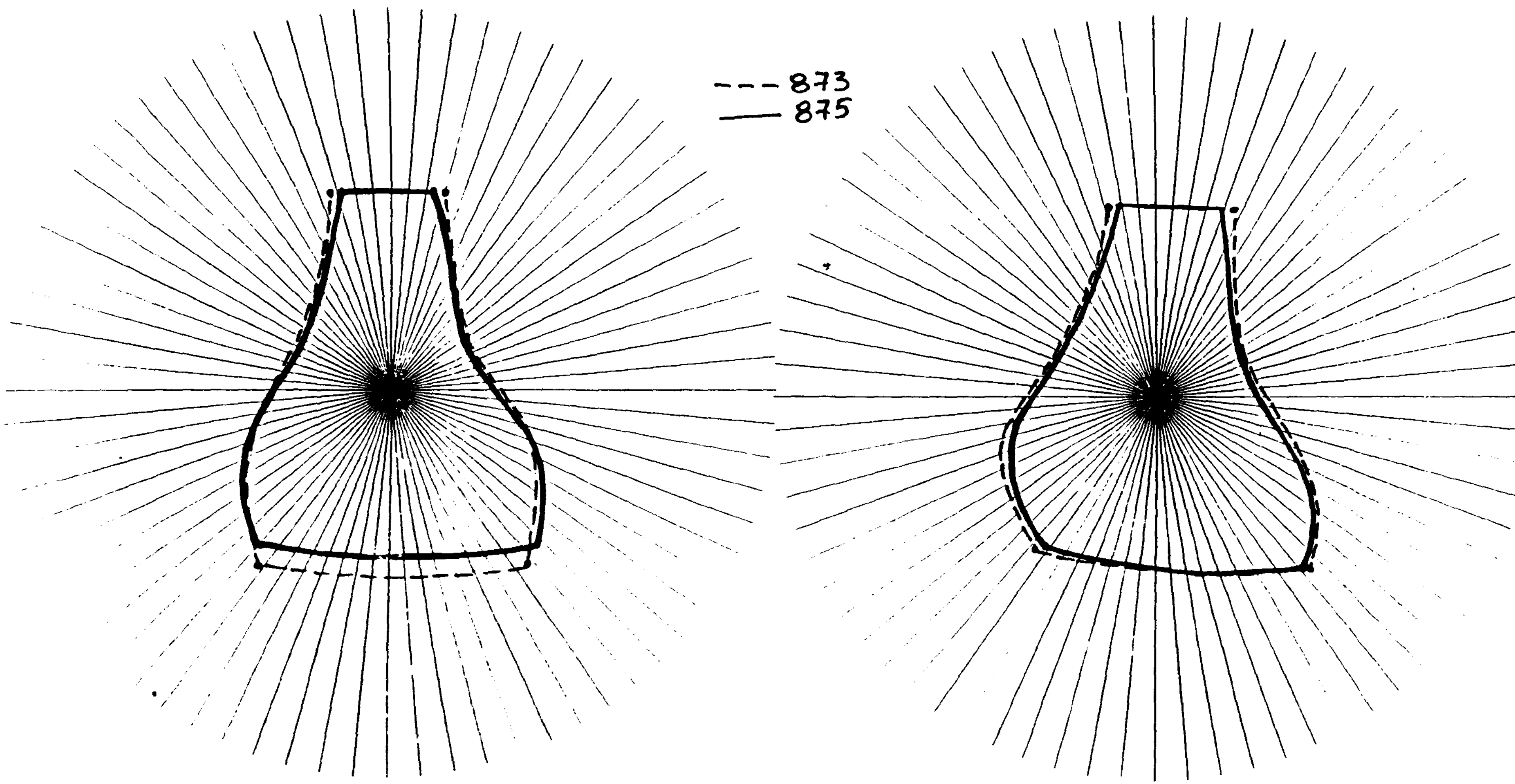


Figure 7.26 Comparison of the lasts sections belonging to seat and shank zones after uprising the seat department for 40 mm

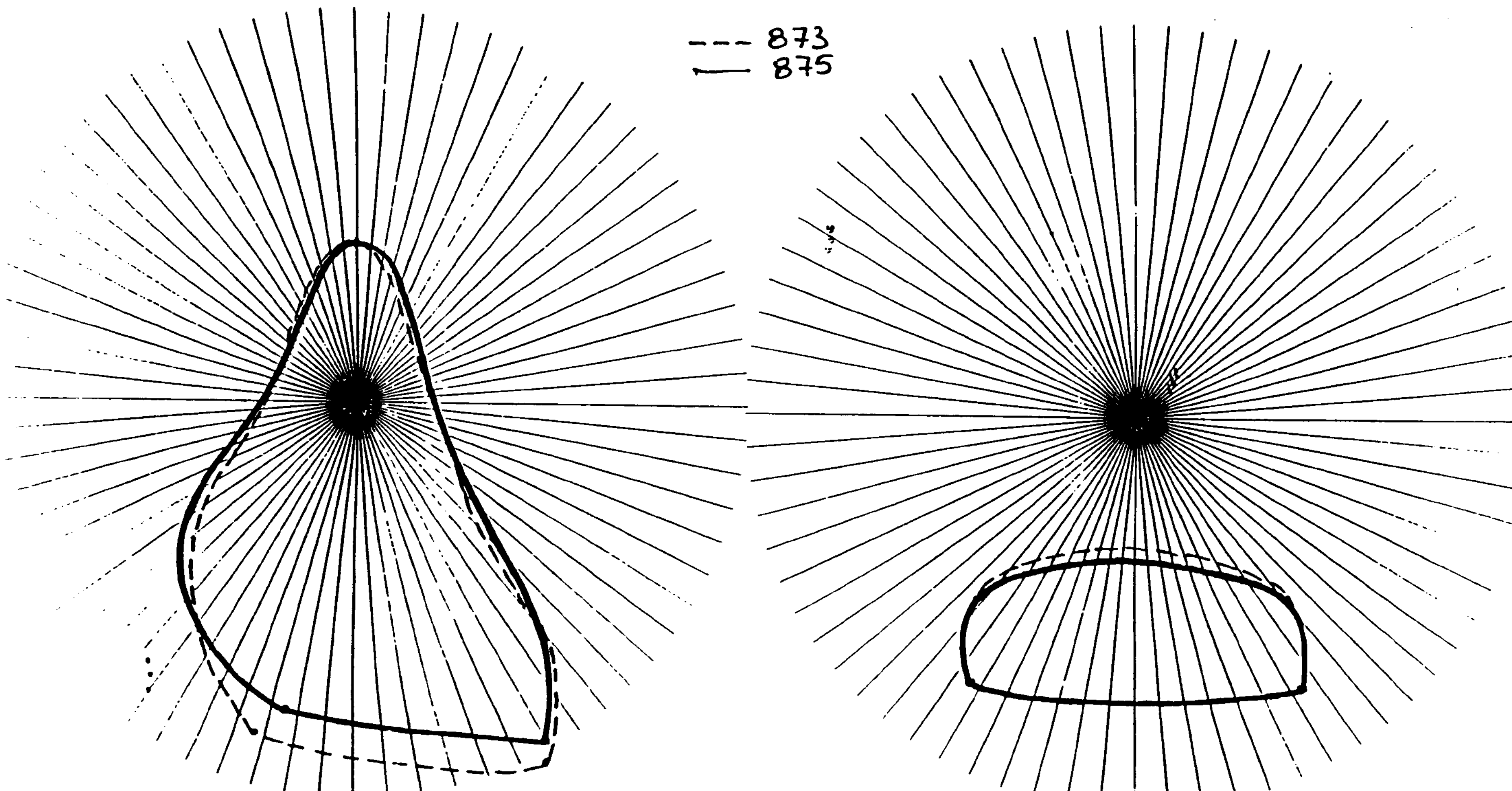


Figure 7.27 Comparison of the lasts sections belonging to ball joint and toes zones after uprising the seat department for 40 mm

The third variant for modifying the heel height represents a combination of two previous approaches. Fig. 7.29 illustrates an experiment for simultaneously changing

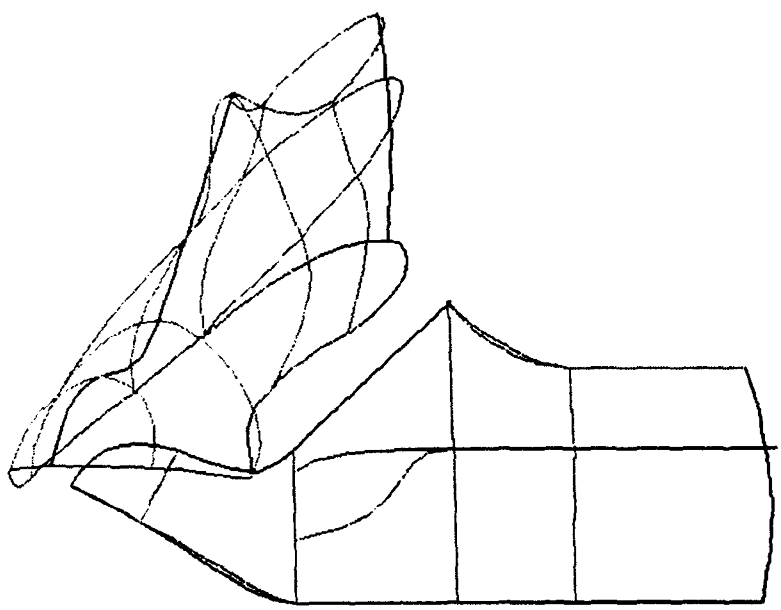


Fig. 7.28 Turning the forepart of the last around axis passing through the tread point

the angle of turning the toe (back-shank) part of the last around the axis passing through the tread point for ***10-11°*** and uprising the back part of the last in parallel to the basic plane by 10 mm. Comparison of transverse-vertical sections from the mathematical simulation model of the last with appropriate sections of the last of model *No 875* (Fig. 7.30 and 7.31) shows a concurrence of contours with an accuracy of within 0,5-0,7 mm (if we take into account the difference between initial sections – Fig. 7.20-7.21 and 7.23-7.24) has been achieved.

Thus, the intermediate experiment for changing the heel height shows that the strongest concurrence of last *No 875* sections with the sections from the mathematical model (with an accuracy of close to 0,5 mm) is obtained by combining the two approaches of turning the toes around the tread point by ***10-11°*** and raising the whole back part of the last up to the section ***0,23L*** for 10 mm in parallel to the basic plane.

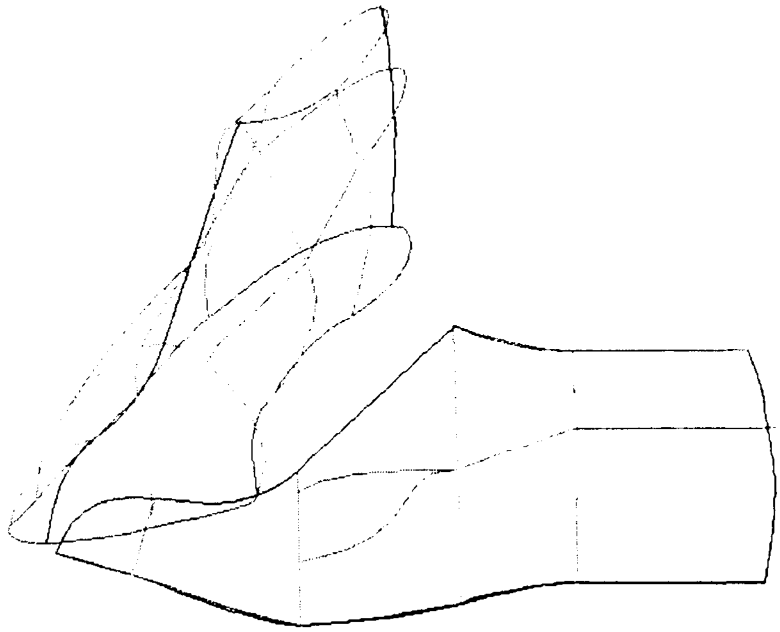


Fig. 7.29 Simultaneous turning the toe part and uprising the back part of the last in parallel to the basic plane

It should be noted that from a biomechanical point of view it is more expedient to use the first variant of a situation by turning the axis of the toe (back-shank) part of the last.

Fig. 7.32 illustrates the result of changing the heel height of the last by the combined approach, with the help of the program 3 DMODIF.EXE (initial data file 2dlst.ini is added with co-ordinates of 3D bottom for reception of the data file 3dlst.ini).

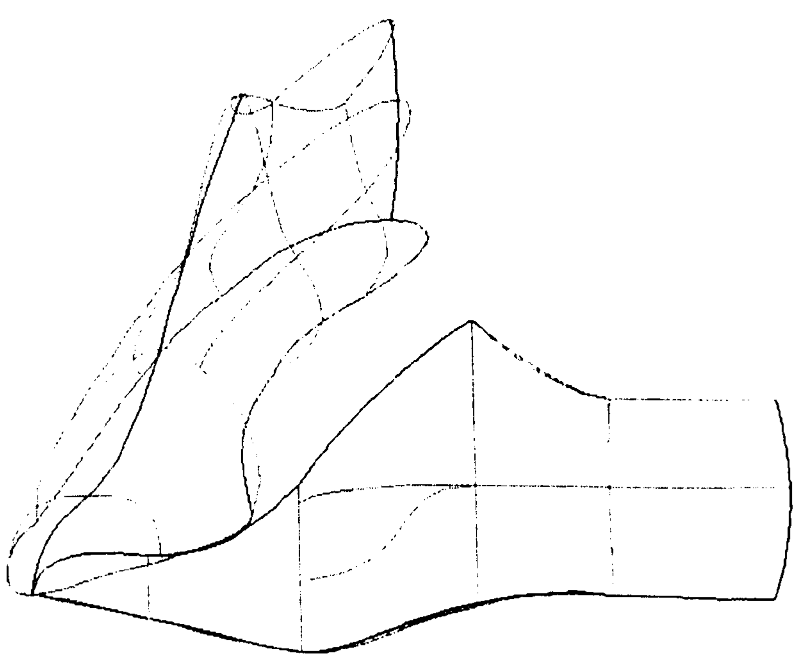


Fig. 7.32 Result of changing the heel height of the last by combined way by the program 3DMODIF.EXE

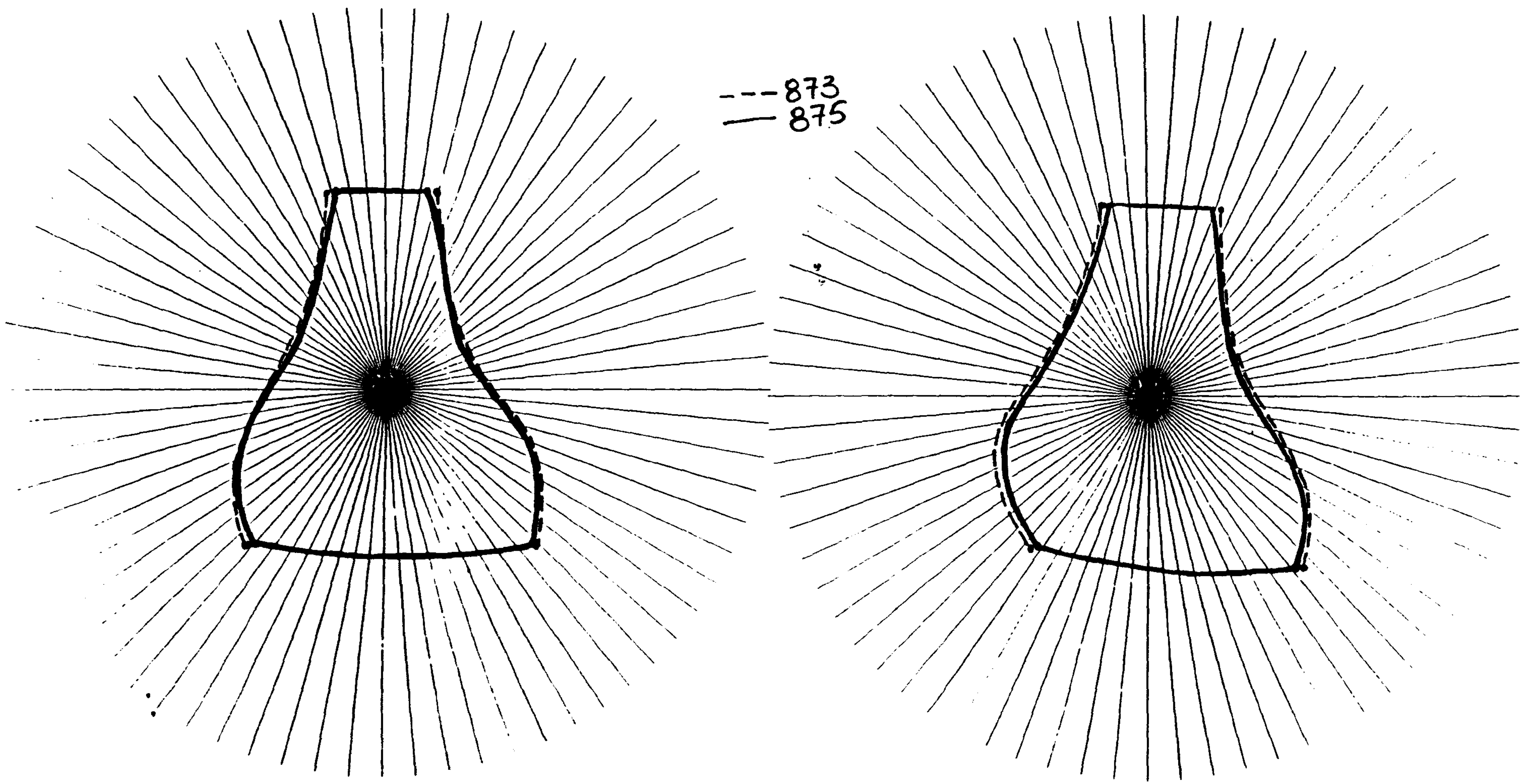


Figure 7.30 Comparison of the lasts sections belonging to seat and shank zones after changing the heel height of the last by combined way

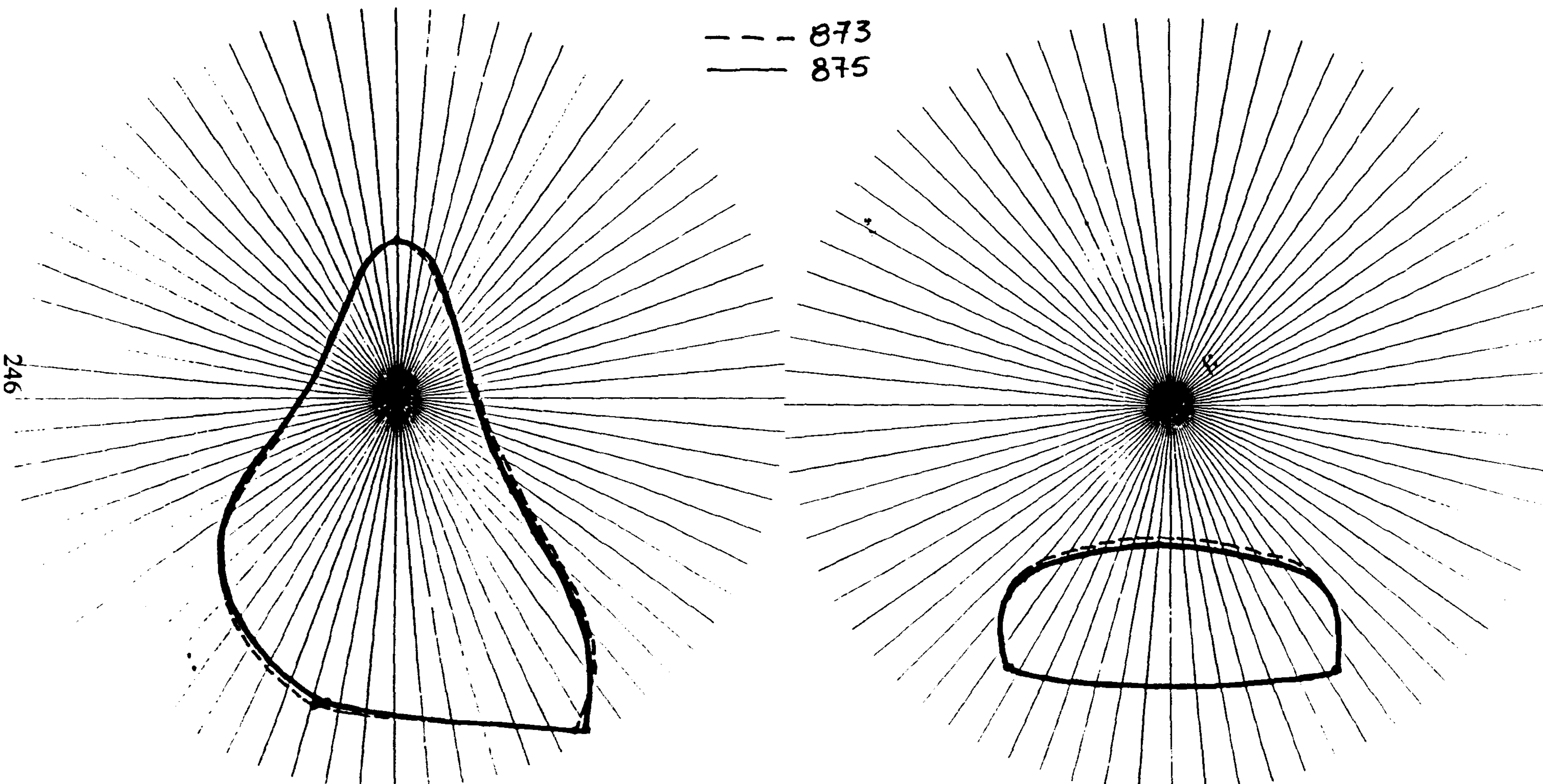


Figure 7.31 Comparison of the lasts sections belonging to ball joint and toes zones after changing the heel height of the last by combined way

7.5.3 Algorithm of manipulating toe spring

The procedure for manipulating the toe spring is similar to the procedure developed in the previous section and consists in turning the forepart of the last around the tread point. However in this case it is necessary to keep in mind that an increase of heel height by 10 mm will decrease the toe spring by 1 mm. Thus, this difference also should be taken into account in any global procedure for changing the heel height.

7.5.4 Algorithm of defining exact position of front cone profile

The direction of the front cone profile corresponds to the direction of the large toe of the foot within footwear and is characterised by slight turning inwards of the last top part. Such construction of the last body meets the requirements experted for normal construction of the last.

With the purpose of generating the exact position of the front cone profile of the last an algorithm for moving the top points of sections "Ball Joint" and "Toes" (6.4) in the direction of the large toe (Fig. 7.33) has been devised (GORDEYEVA and MONCHUCK, 1998).

To define and compare values of displacement the basic points in the two cross-sections 19 ladies lasts of average size have been selected and measured. The results are indicated in the Table 7.4.

Last style	Size and Fit	Height of the heel, mm	Value of displacement in section "Ball Joint", mm	Value of displacement in section "Toes", mm
1	2	3	4	5
316L815 For mules	240;8	50	4	5
326L813	240;4	25	5	4
903	240;4	90	5	4
841L195	240;4	15	5	5
813L532	240;4	30	4	3
313L811	240;4	15	4	4
899	240;4	25	4	4
333L833	240;4	30	4	4
319L821	240;3	20	5	4

1	2	3	4	5
332L821	240;4	5	5	3
821L607	240;4	5	4	4
811L473	240;4	10	4	3
81824M	240;3	20	4	3
3331833	240;3	30	4	4
035710	240;5	35	5	3
315L846	240;5	80	4	3
211448-2G	240;4	25	5	3
418L841	240;4	5	3	3

Table 7.4 Values of displacement the basic points in the cross-sections "Ball Joint" and "Toes" of ladies lasts of average size

Lasts were chosen arbitrary, however, as it is clear from the Table. 7.4 all of them have discrepancy in the location of the last front cone profile relative to the longitudinal-axial section (profile). The value of the ball joint displacement appears to be independent of the heel height and the purpose of footwear verify insignificantly: in section "Ball Joint" – approximately for 4-5 mm, in section "Toes" - for 3-4 mm.

Actually when designing individual lasts, it is necessary to take into account the fact, that the deviation of the direction of a foot large toe from its longitudinal-axial section (taking place through the foot axis of symmetry) has significant value and it is individual in each particular case. Therefore it is seemed rather convenient to use this opportunity, to set any value of displacement of the top points of the cross-sections "Ball Joint" and "Toes" in the initial data file, in an interactive mode.

Thus it is expedient to define the maximum value of moving the top points of cross-sections "Ball Joint" (section ***0,68/0,72L***) and "Toes" (section ***0,90L***) in accordance with the value of deviation of directions of the last stick line and individual foot longitudinal-vertical section conterminous with the direction of the first metatarsus.

With this purpose, it is suggested that it is useful to define the distance between the stick line of the last and an axis passing through the projection of the point of the last profile and cross-section "Front cone profile" intersection and the centre of the big toe (the latter meets the situation of the cross-section "Toes" – ***0,90L***) (Fig. 7.34).

Analysis of 20 plantograms shows that values of deviation of feet with almost average measurements are equal to 20-25 mm in the section "Toes" and 10-15 mm – in the

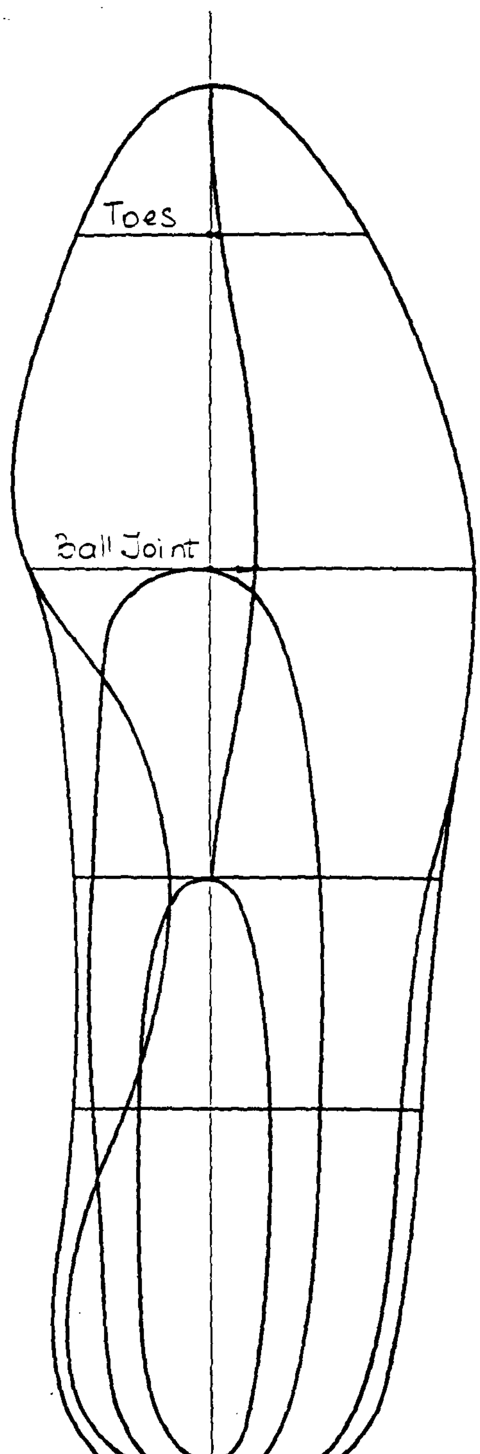


Figure 7.33 Generating exact space positioning of a frontcone profile

section “Ball Joint”. However, as the above analysis of the front cone profile direction in real lasts showed, in practice, the value of the displacement in the two sections did not exceed 3-5 mm.

During further evaluation node points were displaced by 10 and 5 mm respectively in “Ball Joint” and “Toes” (program 3DMODIF.EXE used). These translations led to new sections, which were then compared with the real sections of the original last. Concurrence with accuracy of 0,5 mm was achieved. The highest points of the initial contours in the ball joint and toe sections of the last do not really belong to the longitudinal-vertical section of the last. Thus the research conducted supports the need to use the described procedure, i.e. to generate the front cone profile location with the help of Bezier curves.

Thus, when designing individual last it is recommended to adjust the top node points of the cross-sections “Ball Joint” and ”Toes” within the limits of 3-5 mm up to the maximum value required in each individual case.

7.5.5 Algorithm of shaping profile shank

As is known, the curve of the profile shank of the last should be in accordance with the requirements of footwear manufacturing technology technology (moulded metal shank places in this place). For footwear made on lasts with different heel heights shanks of appropriate forms are used. Hence, when designing a new form of a last on a computer display by changing the heel height, it is necessary to automatically change the course of the curve in the shank area.

To develop the way for setting the standard shape of the shank curve the program GELENOK.EXE was used, the data were recorded into the data file “sec”. The experiment was constructed to use a standard shape in the shank area based upon a good last patterns for an average size but with different heel heights for different age-sexual groups (GORDEYEVA and DEDOVA, 1997). Fig. 7.35 illustrates an example of constructing a contour of a shank curve of the longitudinal-axial section of the last, which consists of two elementary cubic segments.

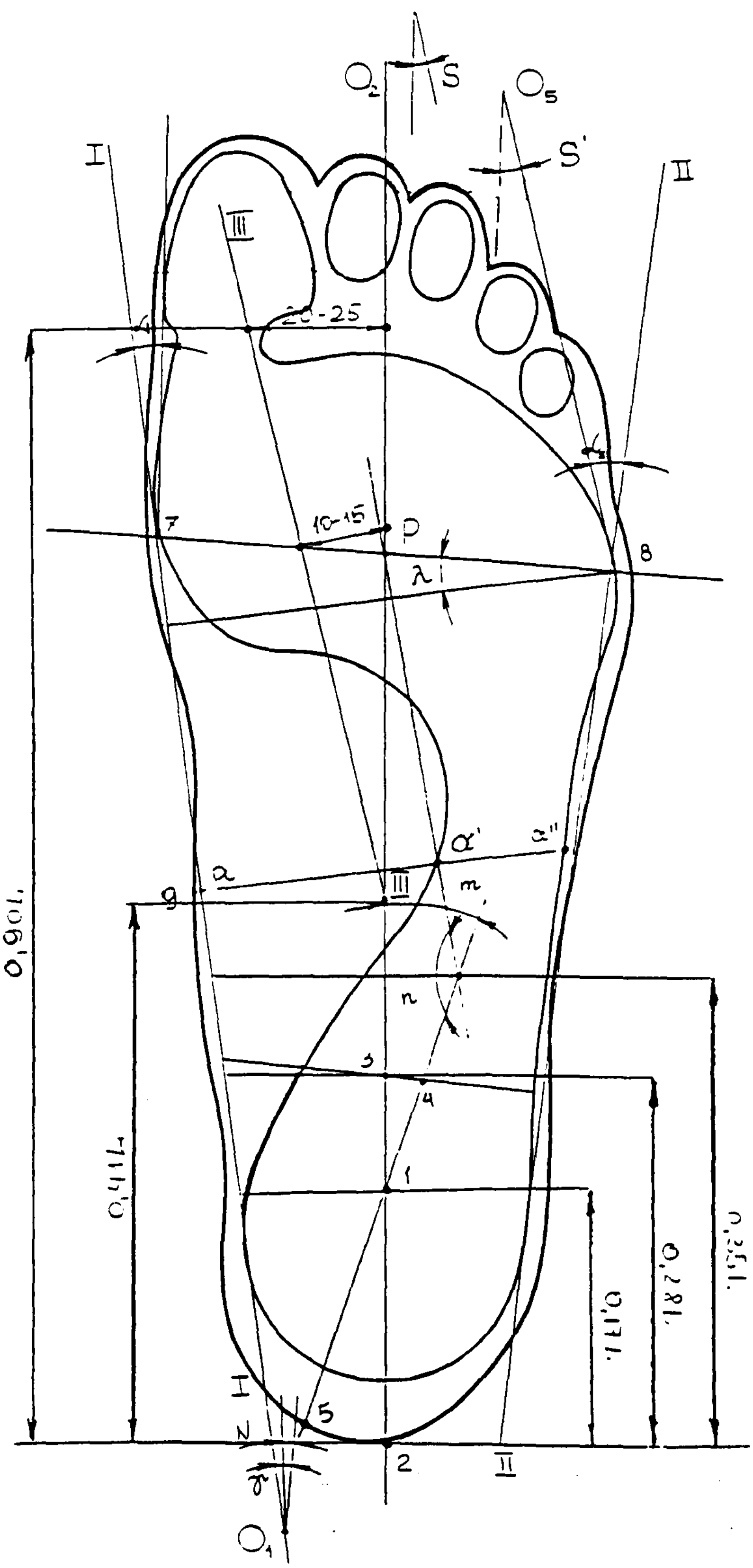


Figure 7.34 Defining maximum value of displacement node points

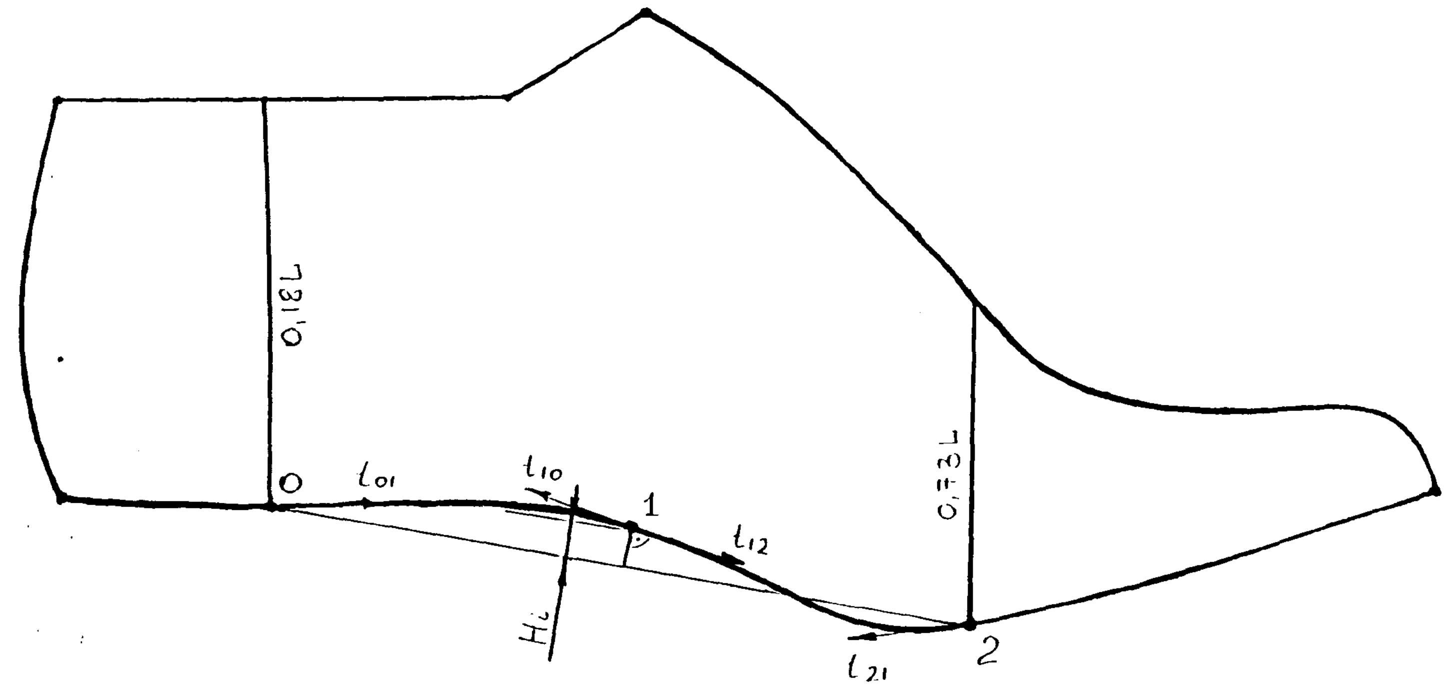


Figure 7.35 Constructing a contour of a shank curve of the last profile

The node points are located in the places of the contour bending (shift of a curvature mark). A derivative vector passes tangentially to curve in the node point. A direction and length of the vector necessary for reception of a needed form of the profile shank contour are set. The basic points and derivative vectors been set their co-ordinates are determined by the drawing which then are recorded into the data file in the form of table 7.5, which illustrates the data for a ladies last with a heel height of 60 mm.

	X (mm)	Y(mm)
7		
0	34	107
t_{01}	67	98
t_{10}	90	80
1	105	60
t_{12}	114	44
t_{21}	127	33
2	146	30

Table 7.5 Data file <sec>

The results of generating the profile shank area of ladies and men's lasts with the heel heights 5-80 mm and 5-40 mm accordingly by method of Bezier curves are indicated in the Appendix J. Comparative analysis of the curves received with the unified shank parts of the profiles of the real lasts has shown a concurrence of contours with the accuracy up to 0,5 mm, that proved the opportunity to generate the shank curve of the profile with high accuracy.

However, the given procedure means manipulating separate node points, that presents inconvenience for unskilled operators. Therefore with the purpose to allow unprepared operators to use the technique offered it is suggested the following approach:

Length of tangent vectors was unified and for ladies and men's lasts accordingly is presented in the Table. 7.6.

	Ladies' (mm)	Men's (mm)
t_{01}	20	25
t_{10}	20	25
t_{12}	20	25
t_{21}	25	25

Table 7.6 Length of tangent vectors for ladies and men's lasts

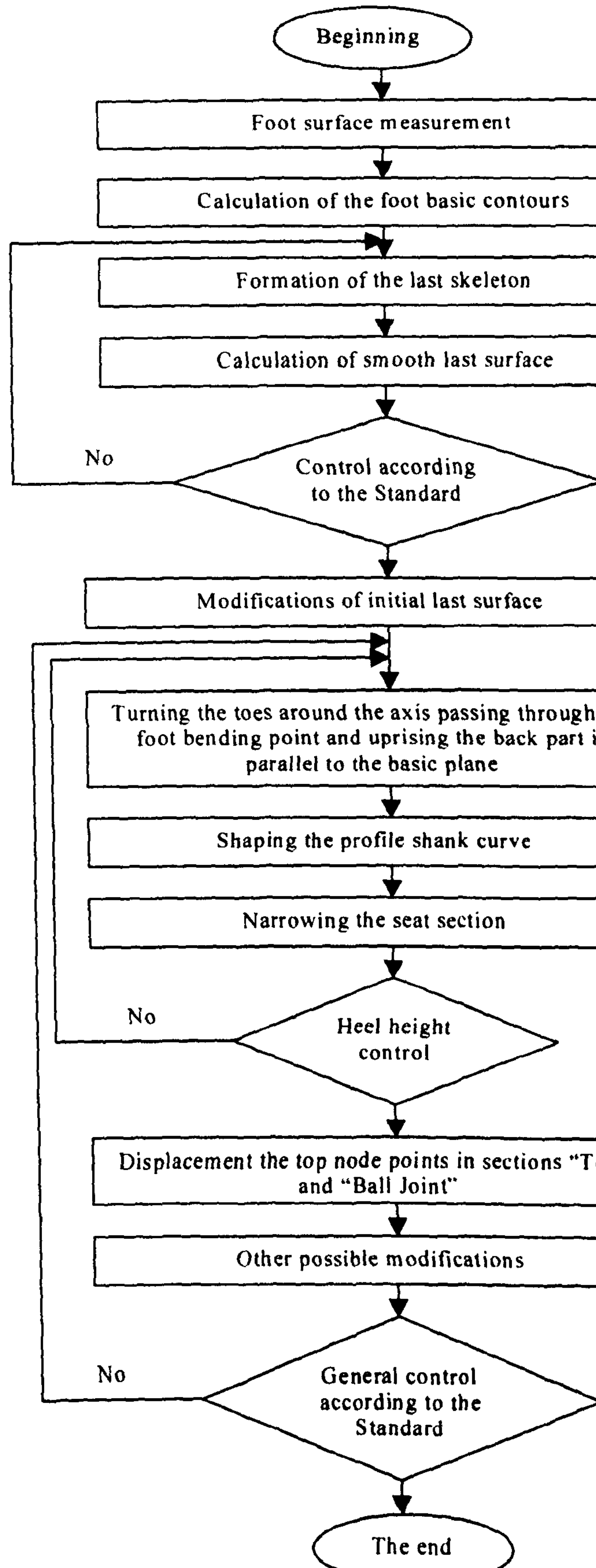


Fig. 7.36 Algorithm of shoe last design

1. The co-ordinates of points ***0*** and ***2*** are calculated automatically in accordance with the locations of the control sections ***0,18L*** and ***0,73L***;

2. The location of point ***1*** is defined by the following law:

$L_1 = L_{02}/2;$

$H_1 = i,$

where i differs according to a footwear size, purpose, design and its heel elevation and is presented in the Table. 7.7 below:

H_e	I_f(mm)	I_m(mm)
5	3.5	5
10	3	7
15	4.5	8
20	4.5	8
25	4.5	8
30		7
35		7.5
40	5.5	7.5
50	4	
60	5.5	
70	6	
80	6	

Table 7.7 Value of *i* for ladies and men's lasts

There was suggested a variant for the location of point ***1*** onto the standard cross-section ***0,55L***, however, in this case it was not possible to unify the length of the vector derivatives.

Thus, in the result obtained from the research into designing a set of patterns of the last basic sections (see chapter 5) and manipulating the global parts of the last surface a method of designing the shoe last directly from anthropometric data with further modifications of its form was developed. The algorithm, realising the method developed, is submitted at Fig. 7.36.

In the result of the research the concurrence of contours with in accuracy of 0,5 mm was achieved. This corresponds to the accuracy of last designing under Russian Standard for lasts (FOOTWEAR LASTS. RUSSIAN STATE STANDARD No 3927-88, 1990) and permits the recommendation of the procedure for application in the area investigated.

Chapter 8. Recommendations and Conclusions

8.1 Recommendations for Further Work

8.1.1 Testing further modifications

A distinct limitation of the work presented is that only five modifications were fully tested. However, the list of possible modifications developed within the project includes at least 14. Moreover, all manipulations were tested in isolation and should be investigated simultaneously as the last shape alters in different directions during even one modification.

Therefor, it is recommended to start further research into the following alterations:

- To define changes in the following sections in relation to changes in the heel height:-
  - last heel curve. The lowest 1/3 part of the heel curve alters according to the quantity of a shift of the last bottom (*S*) concerning the heel point;
  - the bottom pattern length.
  - the ball joint cross-section shape. The perimeter should remain constant be the same, but the higher the heel, the narrower the section in order to prevent foot slipping. This could be easily done by manipulating node points and vector derivatives of corresponding section, however it is recommended to invent global procedure of the modification;
  - the toe cross-section shape. This could be done easily by the same technique as above, but it is again recommended to invent the global procedure (for example, by interactive narrowing/expansion of width of the last bottom in appropriate cross-section by moving the basic points of the bottom); the latter is very important as the toes are the first part of the last subjected to altering according to fashion trends and shoe designers that are often unskilled operators expect to

have this possibility to change the toes shape in different and convenient manners;

- To develop global procedures for changing a degree of supination/pronation and turning inwards/outwards of distal and proximal departments of the last;
- To define the principle and to change the space situation of the bottom contour;
- To turn axis of symmetry of the seat in relation to the stick or the ball joint lines;
- To turn axis of symmetry of the cone top surface in relation to the stick line;
- To turn the line of the ball joint in relation to the stick line;
- To change the ball girth.

8.1.2 Lasts for different age/gender/purpose groups

As the experiments conducted related only to ladies court shoe lasts, further research is required on lasts for different age, gender and purpose groups. For example, the work of Goroch (GOROCH, 1996) was based not only on mathematically described lasts for women's, men's and children's footwear, but also for one type of orthopaedic last. Thus, as the experimental base exists it is recommended to start further work from the application of the method proposed in this thesis to manipulate the lasts shapes in order to additionally evaluate the validity of the methods developed.

8.1.3 Unified software creation

As the last alters its volumetric parameters in different directions during the modification of even one parameter, any global procedures need to take into account all possible shape alterations. Therefore, in order to get the form of a newly designed last, it is necessary to unify all manipulation algorithms. For this, all alterations should be the subject of further research and specially designed software should be developed. The latter could be either made unified or divided into modules and should be of very user-friendly interface allowing designer to design graphically.

8.1.4 Creation of unified CAD system for footwear

The main idea driving this work was the global objective to invent a technique for automated bespoke last design. The methods proposed allow the integration of a *total solution* from scanning of the foot to milling the last and producing the shoe.

However, the last design method from foot data has been proposed in this thesis but not evaluated. The only way is to manufacture the designed last by NC-means and to produce shoes using it. This is the subject for further research.

8.2 Additional Application Areas

Although the methods developed were evaluated on court shoe lasts, they are potentially applicable to different last styles and for footwear with different purposes. Examples of their possible application are described below.

8.2.1 Orthopaedics and prosthetic appliances

Orthopaedics is another area where the manipulation of 3D CAD surfaces can be of significant benefit. Orthopaedic footwear is traditionally individually designed and produced, incurring high cost penalties. The introduction of computer last design methods would reduce the costs of such footwear significantly while increasing the comfort of the finished item. Once designed, the last for a particular patient may be then modified to produce lasts of different styles, purposes or heel height for the same patient that would reduce the cost even further.

A somewhat easier case is for curing footwear related foot disorders. Treatment at an early stage, using prosthetic appliances, have been successfully used (FOOTWEAR FOR PROBLEM FEET, 1973) and these may be designed using individual last constructed by methods described here.

8.2.2 Sport footwear design

Sport footwear is expected to possess both great comfort and specific performance properties for each kind of sport. Here the method of last design from foot data can be of significant benefit, in particular, when designing individual lasts for world leading sportsmen. When bulk producing sport footwear, the method of new last style design by global last modifications may be applied and particular attention paid to the last form for different kinds of sport.

8.2.3 Grading facilitating

As procedures of co-ordinate grading are similar to those proposed in this thesis for turning the last parts, the principles and approaches of the latter procedures may be applied in order to grade lasts in 3D when designing a last for an average foot and then processing it by NC-means.

8.2.4 Standardisation of lasts shapes

As chapter 4 shows some of the 3D CAD/CAM systems offer surface creation and modification facilities using standard parts of lasts. One of those facilities is last blending, where sections of two digitized lasts are combined to form a third. It involves taking the backpart of one last and the forepart of another and defining a blending region between the two.

This concept could be further developed using the software used in the work. It requires the combination of two data files into one without defining any blending region as a Bezier surface is guaranteed to be smooth between the boundary sections. However, combining the two data files is an inconvenient way to design. A new variation may be the creation a new version of software that will allow the combination of data files in interactive mode.

Thus, the application of methods proposed in the work allows the manipulation of global sites of the last surface for creation of new styles with the standard elements of the form, to accumulate the libraries of unified last parts, moulded details and units, surfaces of the tooling.

8.3 Conclusions

8.3.1 Main conclusions drawn from the work

Have studied all the information available related to the thesis subject and finished the experiments it is possible to draw the following conclusions.

1. The analysis of modern situation in the field of automation of footwear design and manufacture processes has shown that the main tendency of development of CAD/CAM technology for footwear is the creation of a uniform system for computer design of footwear on the basis of individual anthropometric data.

2. CAD/CAM systems combine advantages of hand-operated method of footwear production: an opportunity of complete design of the form and contours of footwear by one person and taking into account individual feet, and factory method: an opportunity of decreasing labour intensity at the expense of automating manufacturing. CAD/CAM has become a beneficial everyday tool enabling rapid change of assortment and resulting in significant savings in materials and labor and producing better shoes.

3. However, limited use of 3D systems in shoe manufacture is marked in comparison with extensive use of cheaper 2D systems. It is connected to the fact that the basis for 3D designing a last is still made manually. Although systems model the last, none of them are able to create the 3D last surface directly from the foot measurements or on-screen from minimum foot datum. This constrains development of modern methods of automated footwear designing.

4. The work principles of modern CAD/CAM systems for footwear and graphic software for designing complex 3D freeform objects (in particular, MicroStation software) were evaluated in order to determine an opportunity for the application of existing CAD/CAM systems using standard graphic software. Their limitations are characteristic for the majority of the shelf CAD packages and proved the requirement to develop bespoke software for designing the shoe last and to use the uniform mathematical apparatus at all stages of designing.

5. The methods of surface mathematical description used at present within modern CAD/CAM systems are unsuitable for the purposes of manipulating the last surface at designing. Bicubic polynomials in Bezier form were chosen as the optimal mathematical apparatus for the last surface description at designing the last based on individual foot data. Thus, Bezier formula is convenient for hand-operated manipulation of the curve course since it permits to purposefully operate the character of the surface at preservation its smoothness and curvature and to provide smooth change of curvature for large surface patches. Using the apparatus chosen the last mathematical model has been generated.

6. There is inconsistency in the approach to modelling shoes and lasts. However, studying the traditional techniques of designing the volumetric shape of the last and using the experimental technique for measuring the individual foot, it has been possible to reflect on the rationality or, on the contrary, discrepancy of particular techniques of the last element design, to reveal the main laws of forming the lasts of different purposes and have proven the necessity to develop the uniform approach to designing the shoe last in a computer environment on the basis of individual foot data. On the basis of materials studied and experiments conducted the fundamentals of last design on the basis of anthropometric data have been elaborated.

7. In the result of experiments conducted on designing the last, a universal method of designing the lasts of various purposes from individual anthropometric data in view of the requirements, presented to the rational last shape, has been developed. With the purpose of approbation of the method developed an individual last for ladies' court shoes has been designed.

8. A new segmentation scheme for lasts with horizontal cone top plane has been proposed, where the location of transverse-vertical sections "seat" and "toes" have been replaced on the location of the standard sections ***0,18L*** and ***0,9L*** relatively. The results of experiment of computer last surface modelling for individual foot measured have proved the possibility of application the method developed and validity of newly offered scheme of segmentation.

9. The research was conducted aiming at revealing the difference of geometrical parameters of ready-made lasts of similar styles but with various heel height (in

particular, 40 and 80 mm) have allowed to empirically define the laws of forming the last shape at changing the heel height and to develop the list of possible modifications of the global patches of the last surface enabling to create the new last style. The procedures are global manipulations in comparison with the methods of manipulating points and vectors but also permit to manipulate the separate large elements of the last more exactly and correctly by customary and clear for shoe designers ways.

10. For realization of the method proposed a special software in language <Turbo C> has been developed.

11. The axes and angles of turning the last toe or seat-shank parts have been determined with the purpose of changing the heel height. Thus, various rules and approaches of changing the last heel height and toe spring have been developed and, therefore the variant of simultaneous turning the toe part around the axis passing through the foot bending point and uprizing the back part in parallel to the base plane has been proposed.

12. Rules and approaches of narrowing the seat section of the last at increasing the heel; generating the real space course of the frontcone profile of the last, having a character of slight turning inwards, and shaping the last profile shank curve have been developed.

13. The researches conducted of behaviour of a volumetric last surface at various manipulations have allowed to develop a method of designing the shoe last from anthropometric data by modifying its form on a computer display.

14. Recommendations for use of the methods proposed for the purposes of computer shoe last designing have been developed.

15. Using the global procedures of last patch manipulation allows non-computer literate designers to use the techniques proposed in the work when using computer footwear design systems.

Automation of the processes of the last designing and production confirms the efficiency of creating direct computer last design system.

8.3.2 Scientific contribution to original knowledge

Scientific contribution to original knowledge of the technique proposed for the last shape designing and manipulating consists in the following:

1. A transfer method from the average foot (or from individual foot in particular case) to the last on the basis of available data has been developed with further last designing.
2. The integration and application of existing designing methods to individual data (instead of average foot data as in traditional techniques) with the purpose of creation a quite new last style with further recommendations of the methods improvements have been done.
3. The new segmentation scheme for lasts with horizontal cone top plane has been proposed.
4. The last designed mathematical model was generated.
5. The last shape forming principles were determined.
6. The list of possible last surface global patches manipulations has been developed.
7. Parameters of changing the angles of turning different parts of the last were defined.
8. Positions of axes of turning last toe or shank-back part have been found out.
9. Rules of simultaneous narrowing the seat section of the last at increasing the heel have been developed.
10. Procedure of changing the heel height has been devised.
11. Rules and approaches of generating the real space course of the frontcone profile of the last, having a character of slight twisting inwards, have been developed.
12. Several variants of shaping the last profile shank curve between the cross-sections 0,18L and 0,73L have been developed.
13. A method of designing the shoe last from anthropometric data by modifying its form on a computer display has been invented.

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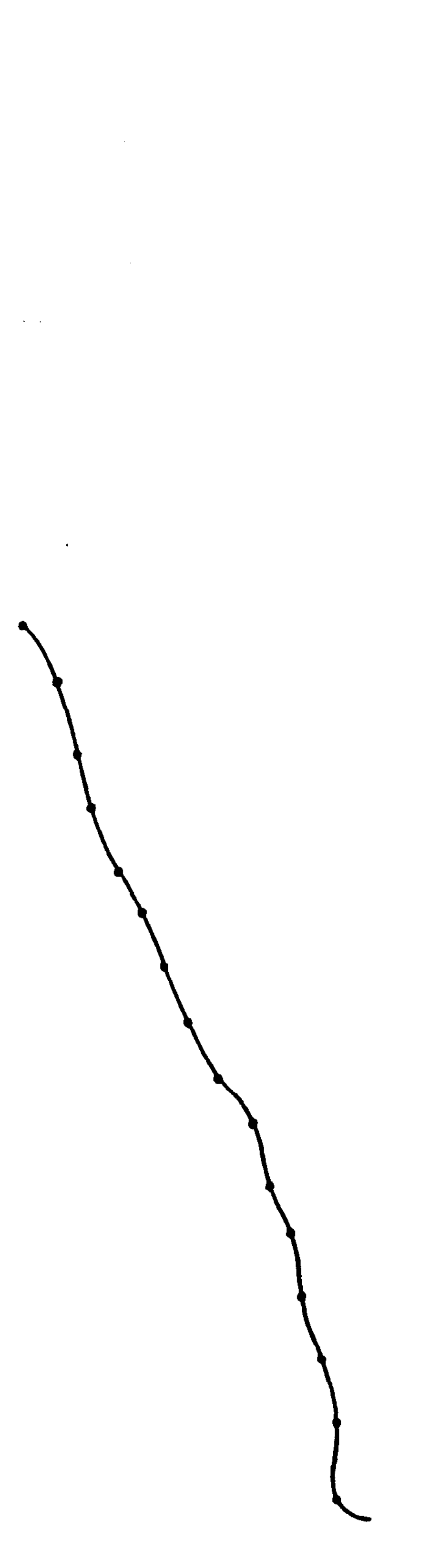
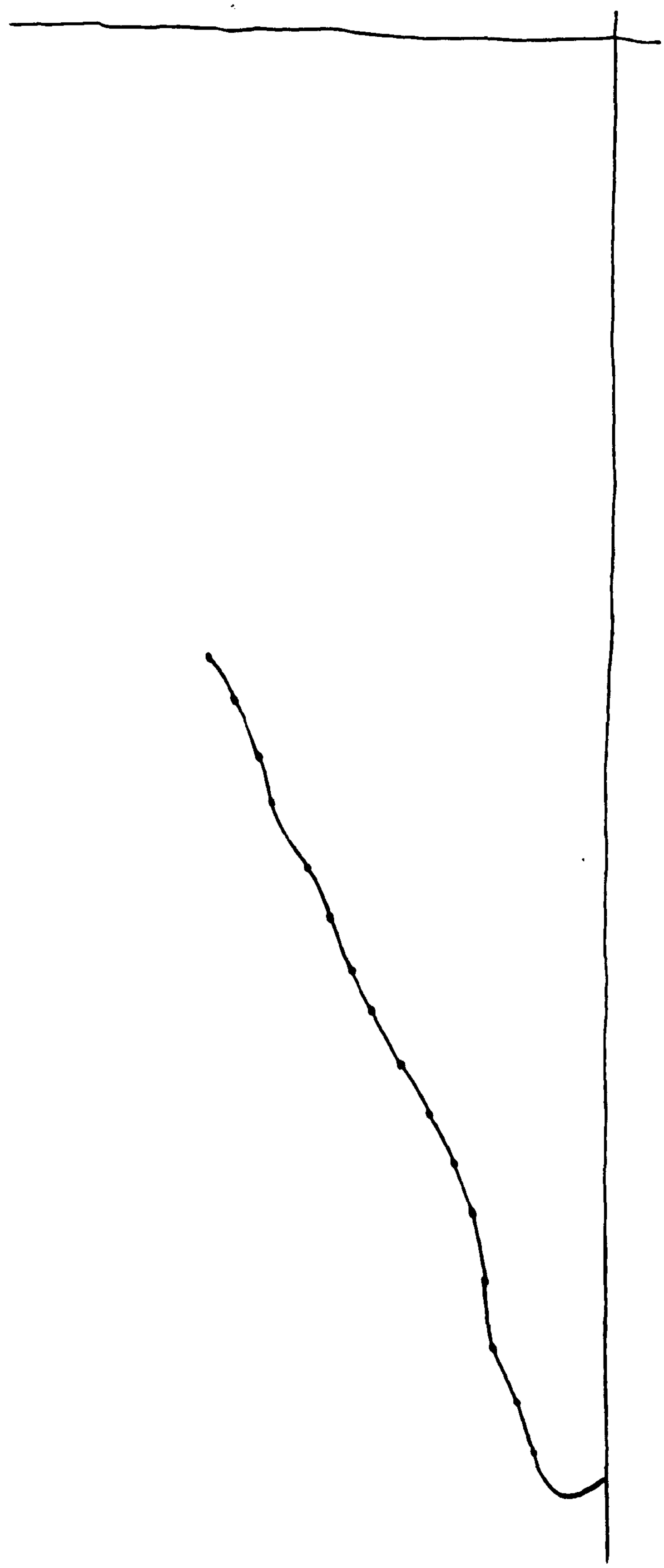
Appendix A – Profiles and Cross Sections

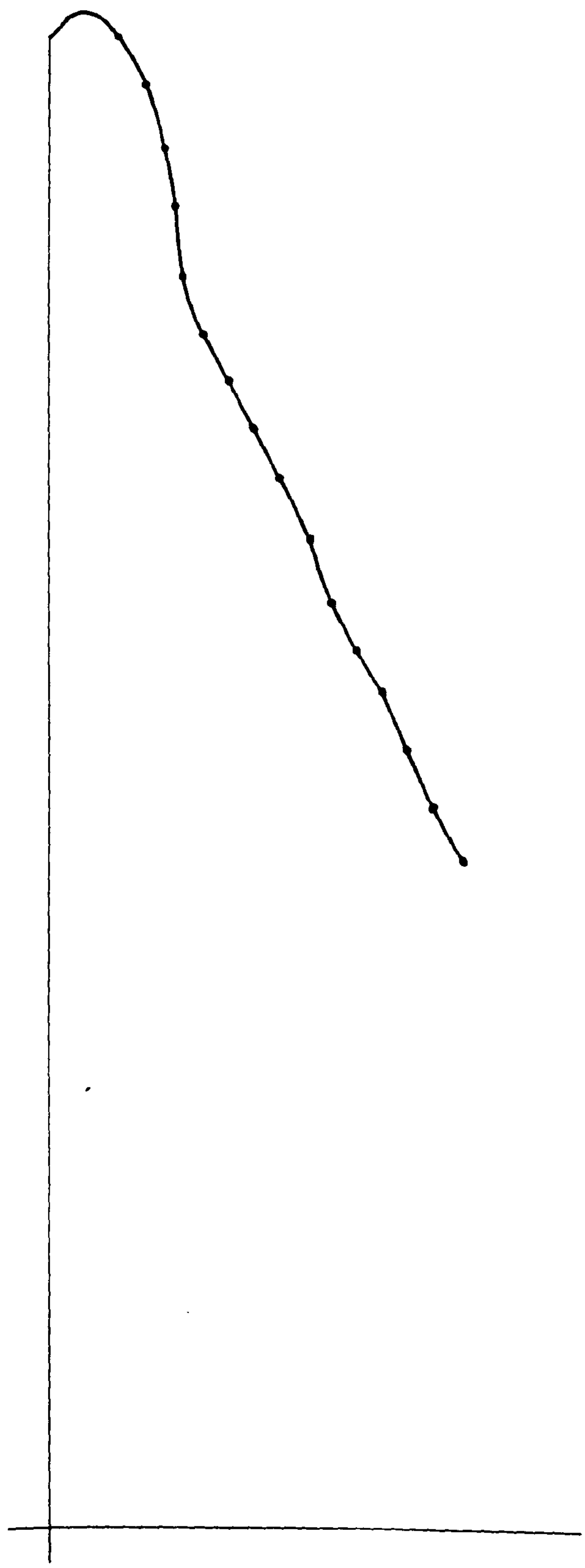
A.1 The Foot Front Cone Profile



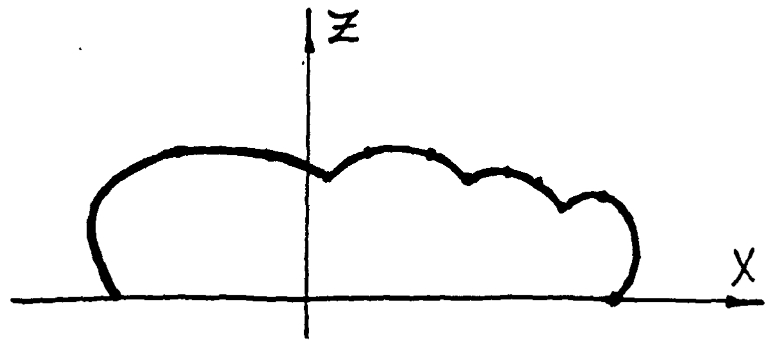
A.2 The Foot Profile



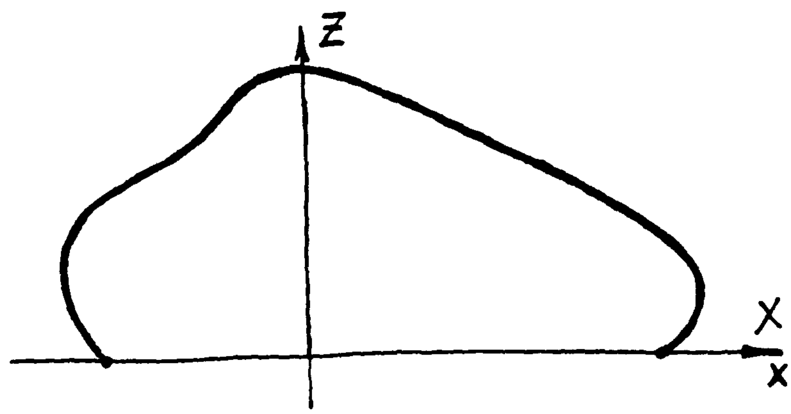
A.3 The Foot Transversal-Axial Section, Passing Through The Foot Axis Of Symmetry



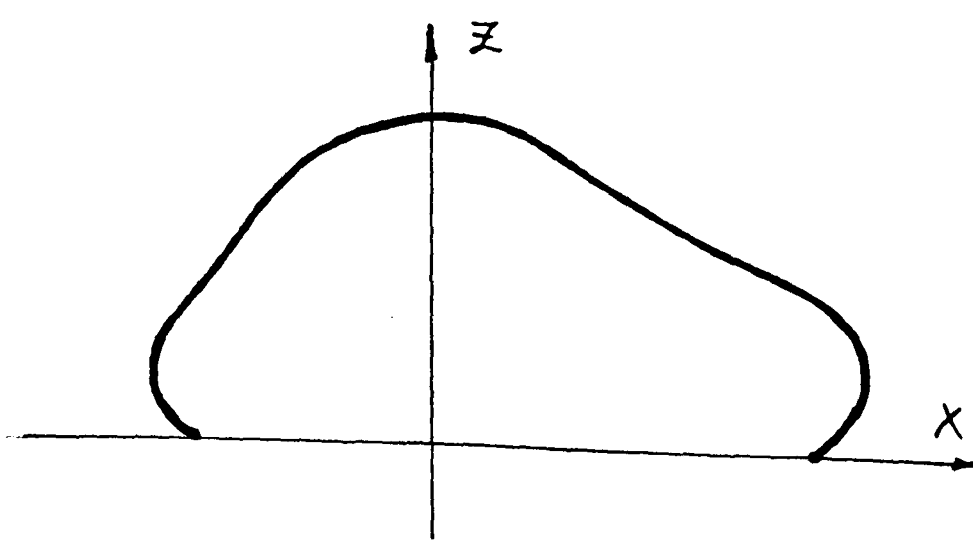
A.4 The Foot Cross-Section 0,90L



A.5 The Foot Cross-Section 0,73L

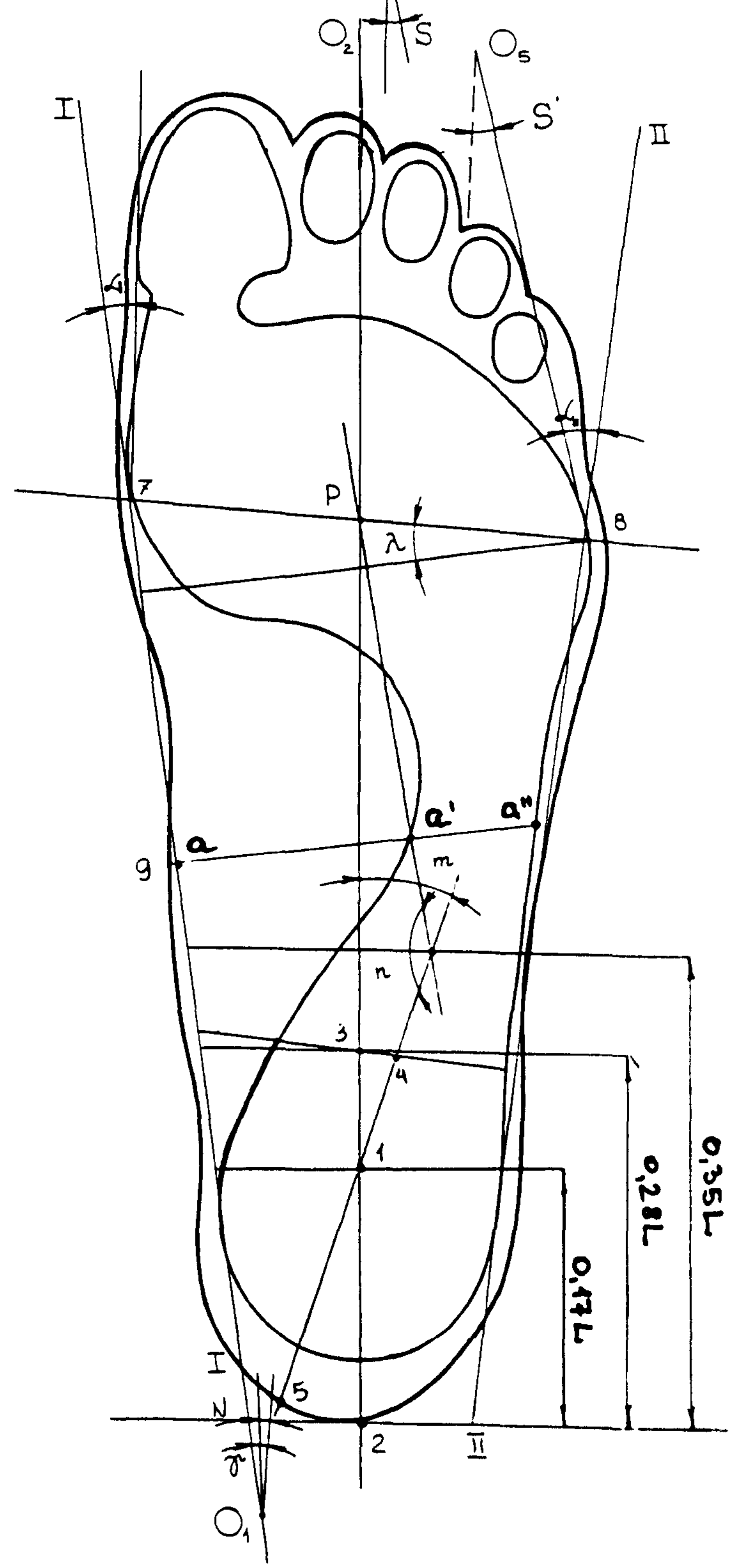


A.6 The Foot Cross-Section 0,68L

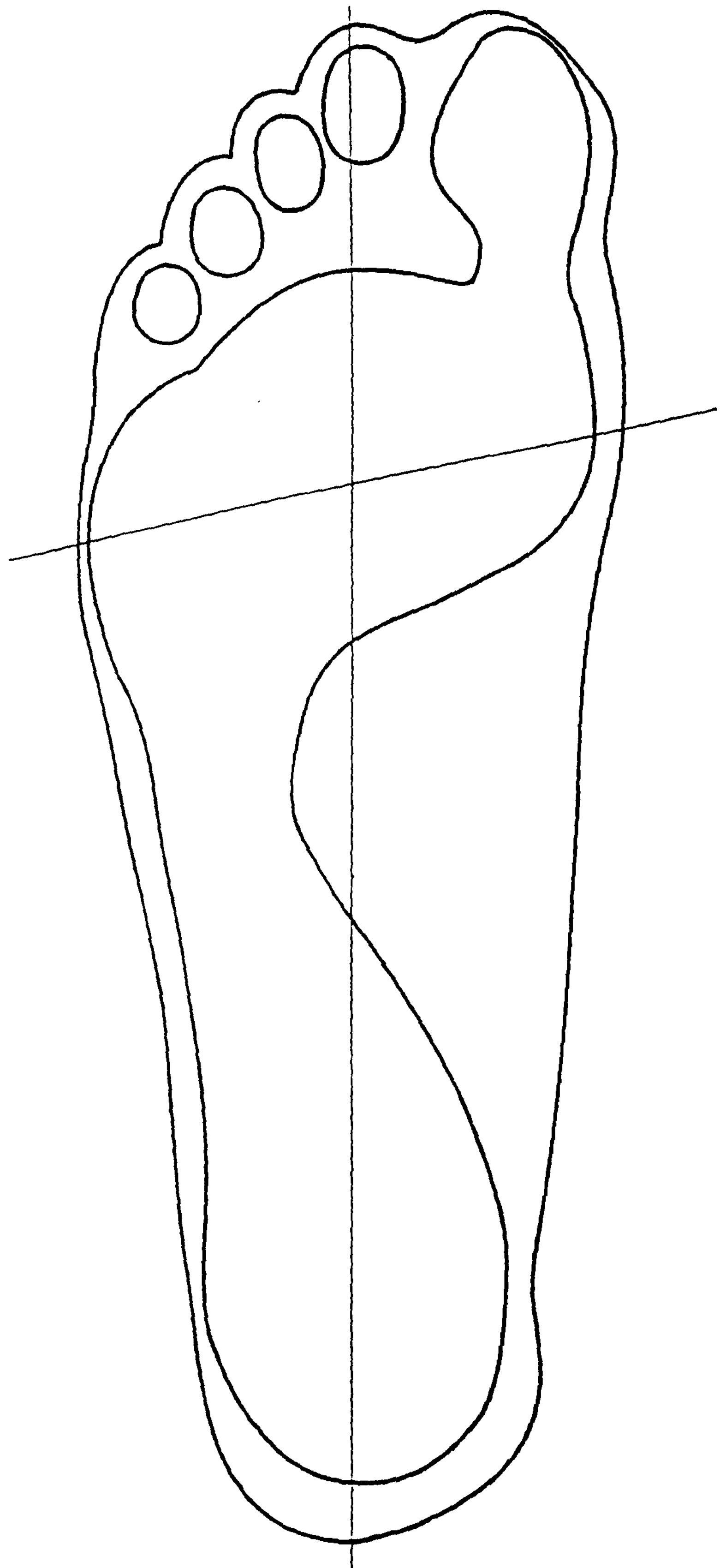


Appendix B – Plantograms

B.1 Right Foot Plantogram



B.2 Left Foot Plantogram



Appendix C

```
#include <dos.h>
#include <stdio.h>
#include <graph.h>
#include <stdlib.h>
#include <math.h>

void main( void )
{
int kColor;
float x,y,z,U,V;
int l,k,i,j;
float a[4][4];
float r[4][4][4];

FILE *stream;



stream=fopen("srf1","rt");
if( stream==NULL ) exit(1);

for(i=0; i<4; i++)
  for( j=0; j<4; j++)
    fscanf(stream,"%f %f %f\n",&r[i][j][1],&r[i][j][2],&r[i][j][3]);
fclose(stream);

_setvideomode(_VRES16COLOR);
  for(k=0; k<21; k++)
    {
    U=(float)k/20.0;
    for(l=0; l<51; l++)
          {
          V=(float)l/50.0;
          a[0][0]=(1.0-U)*(1.0-U)*(1.0-U)*(1.0-V)*(1.0-V)*(1.0-V);
          a[0][1]=3.0*U*(1.0-U)*(1.0-U)*(1.0-V)*(1.0-V)*(1.0-V);
          a[0][2]=3.0*U*U*(1.0-U)*(1.0-V)*(1.0-V)*(1.0-V);
          a[0][3]=U*U*U*(1.0-V)*(1.0-V)*(1.0-V);
          a[1][0]=(1.0-U)*(1.0-U)*(1.0-U)*3.0*V*(1.0-V)*(1.0-V);
          a[1][1]=3.0*U*(1.0-U)*(1.0-U)*3.0*V*(1.0-V)*(1.0-V);
          a[1][2]=3.0*U*U*(1.0-U)*3.0*V*(1.0-V)*(1.0-V);
          a[1][3]=U*U*U*3.0*V*(1.0-V)*(1.0-V);
          a[2][0]=(1.0-U)*(1.0-U)*(1.0-U)*3.0*V*V*(1.0-V);
          a[2][1]=3.0*U*(1.0-U)*(1.0-U)*3.0*V*V*(1.0-V);
          a[2][2]=3.0*U*U*(1.0-U)*3.0*V*V*(1.0-V);
          a[2][3]=U*U*U*3.0*V*V*(1.0-V);
          a[3][0]=(1.0-U)*(1.0-U)*(1.0-U)*V*V*V;
          a[3][1]=3.0*U*(1.0-U)*(1.0-U)*V*V*V;
          a[3][2]=3.0*U*U*(1.0-U)*V*V*V;
          a[3][3]=U*U*U*V*V*V;
          x=0.0; y=0.0; z=0.0;
          for( i=0; i<4; i++)
            {
            for( j=0; j<4; j++)
               {
```

```
                    x=x+a[i][j]*r[i][j][1];
                    y=y+a[i][j]*r[i][j][2];
z=z+a[i][j]*r[i][j][3];
                    }
            }
           _setcolor(15);
           _setpixel( (int)(2.6*(x+0.7*y)+320.0), (int)( (-1.8*(z+0.7*y)+240.0)) );
           }
    }
printf("Finished.\n");
 getch();

exit(0);
}
```

Appendix D

3Dlst.ini Data File For The Individual Last

;Location of adjustment points		
right side		3
left side		3
;VGA-14" 22,22; EGA 22,15		
;screen scale tuning		
horizontal size		26
vertical size		25.2
displacement to the left		40
displacement down		480
;Global modifications		
toes turning		0.5
heel height		40
displacement in toe section		10
displacement in ball joint section		5
heel point		22.5
;Table 1 "Bottom"		
heel point	x	0
	y	262
;Node points		
left heel	x	25
	y	222.5
	z	22.5
right heel	x	-30
	y	222.5
	z	22.5
left shank	x	12
	y	135
	z	7.5
right shank	x	-43
	y	135
	z	6
left ball joint	x	39
	y	96
	z	4
right ball joint	x	-46
	y	96
	z	4
left forepart	x	32
	y	53
	z	13.5
right forepart	x	-32
	y	53
	z	13.5

toe point	x	0
	y	16
	z	25.5
; "0" derivatives		
left heel	x	20
	y	260
	z	22.5
right heel	x	-15
	y	260
	z	22.5
left shank	x	11
	y	167
	z	22.5
right shank	x	-35
	y	185
	z	22.5
left ball joint	x	26
	y	114
	z	1
right ball joint	x	-45.5
	y	120
	z	-2
left toes	x	39
	y	85
	z	5.5
right toes	x	-44
	y	85
	z	4
left forepart	x	25
	y	34
	z	19.5
right forepart	x	-25
	y	34
	z	19.5
;"1" derivatives		
left heel	x	29
	y	235
	z	22.5
right heel	x	-26
	y	250
	z	22.5
left shank	x	2
	y	152
	z	13
right shank	x	-40
	y	160
	z	20.5
left ball joint	x	38
	y	110
	z	2

right ball joint	x	-48
	y	101
	z	4.5
left toes	x	40
	y	75
	z	7
right toes	x	-38
	y	65
	z	11
left forepart	x	9.5
	y	16
	z	25.5
right forepart	x	-9.5
	y	16
	z	25.5
;Table2 "Profile"		
;Individual Last, size 240		
heel point	y	260
	z	22.5
waist	y	268
	z	49.5
cone top plane	y	262
	z	88.5
heel	y	222.5
	z	88.5
shank	y	135
	z	88.5
ball joint	y	96
	z	49.5
forepart	y	53
	z	39.5
toe point	y	16
	z	25.5
;"0" derivatives		
waist	y	262
	z	32
cone top plane	y	268
	z	61.5
heel	y	250
	z	88.5
shank	y	180
	z	88.5
ball joint	y	118
	z	72.5
toes	y	84
	z	37.5
forepart	y	23
	z	41.5
;"1" derivatives		
waist	y	268

	z	41.5
cone top plane	y	267
	z	75.5
heel	y	235
	z	88.5
shank	y	140
	z	88.5
ball joint	y	110
	z	62.5
toes	y	70
	z	37.5
forepart	y	20
	z	39.5
;Table 3 "Cone top plane"		
; Individual Last, size 240		
height of the heel	z	88.5
height of the shank	z	88.5
cone top plane point	x	0
	y	262
left heel	x	12
	y	222.5
right heel	x	-9
	y	222.5
shank	x	0
	y	135
;"0" derivatives		
left heel	x	6
	y	262
right heel	x	-5
	y	262
left shank	x	13
	y	185
right shank	x	-9
	y	185
;"1" derivatives		
left heel	x	10.5
	y	250
right heel	x	-8.5
	y	250
left shank	x	5
	y	135
right shank	x	-6
	y	135
;Table 4 "Waist"		
; Individual Last, size 240		
height of the waist	z	49.5
waist point	x	0
	y	268
left heel	x	22
	y	222.5

right heel	x	-18
	y	222.5
left shank	x	25.5
	y	135
right shank	x	-23.5
	y	135
ball joint	x	0
	y	96
;"0" derivatives		
left heel	x	12
	y	268
right heel	x	-11
	y	268
left shank	x	23
	y	200
right shank	x	-20
	y	200
left ball joint	x	26
	y	120
right ball joint	x	-25
	y	110
;"1" derivatives		
left heel	x	20
	y	250
right heel	x	-18
	y	250
left shank	x	24.5
	y	160
right shank	x	-22.5
	y	160
left ball joint	x	20
	y	96
right ball joint	x	-17.5
	y	96
;Table 5 "Girths"		
; Individual Last, size 240		
;Table 5.1 "Heel"		
"y" of the heel	y	222.5
;"0" derivatives		
left bottom	x	26.5
	z	43.5
right bottom	x	-31.5
	z	34.5
left frontcone profile	x	11.5
	z	74.5
right frontcone profile	x	-11
	z	62.5
;"1" derivatives		
left bottom	x	31.5
	z	36.5

right bottom	x	-27
	z	34.5
left frontcone profile	x	11
	z	62.5
right frontcone profile	x	-10.5
	z	74.5
;Table 5.2 "Shank"		
"y" of the shank	y	135
;"0" derivatives		
left bottom	x	34
	z	35.5
right bottom	x	-48.5
	z	19.5
left frontcone profile	x	7.5
	z	88.5
right frontcone profile	x	-8.5
	z	75.5
;"1" derivatives		
left bottom	x	40.5
	z	23.5
right bottom	x	-33.5
	z	32
left frontcone profile	x	7
	z	78
right frontcone profile	x	-10
	z	88.5
;Table 5.3 "Ball joint"		
"y" of the ball joint	y	96
;"0" derivatives		
left bottom	x	21
	z	49.5
right bottom	x	-50.5
	z	21.5
;"1" derivatives		
left bottom	x	45
	z	21.5
right bottom	x	-9
	z	49.5
;Table 5.4 "Toes"		
"y" of the toes	y	53
;"0" derivatives		
left bottom	x	20
	z	39.5
right bottom	x	-31
	z	25
;"1" derivatives		
left bottom	x	32
	z	28
right bottom	x	-20
	z	39.5

Appendix E

Shoe Last No 873 Measurement Data

(Size: 38,5; Stick length: 254 mm)

Cross-Section Number: 1
Step of measurement: 0
Distance from the Heel Point: -5

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	75,77	75		150		225		300	
5		80		155		230		305	
10		85		160		235		310	
15		90		165		240		315	
20		95		170		245		320	
25		100		175		250		325	
30		105		180	55,20	255		330	
35		110		185		260		335	
40		115		190		265		340	
45		120		195		270		345	
50		125		200		275		350	
55		130		205		280		355	
60		135		210		285		360	
65		140		215		290			
70		145		220		295			

Cross-Section Number: 2
Step of measurement, mm: 5
Distance from the Heel Point, mm: 0

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	25.36	75	16.25	150	-	225	17.91	300	20.40
5	25.52	80	15.88	155	-	230	16.80	305	21.45
10	24.50	85	15.49	160	-	235	16.34	310	22.38
15	24.03	90	15.38	165	27.44	240	16.06	315	23.07
20	23.98	95	15.13	170	35.37	245	15.87	320	23.49
25	26.62	100	14.93	175	-	250	15.55	325	23.89
30	22.06	105	14.83	180	43.30	255	15.54	330	24.52
35	21.47	110	14.60	185	43.16	260	15.89	335	25.01
40	20.69	115	15.02	190	-	265	15.92	340	25.18
45	21.39	120	15.26	195	33.76	270	16.38	345	24.75
50	19.04	125	15.46	200	28.13	275	16.90	350	24.52
55	18.47	130	15.89	205	-	280	17.23	355	24.18
60	17.64	135	16.53	210	-	285	17.96	360	25.08
65	17.42	140	17.53	215	-	290	18.67		
70	17.00	145	-	220	-	295	19.82		
						Cone Top Plane		174°26'	41.04
						Cone Top Plane		190°44'	42.42

Cross-Section Number: 3
Step of measurement, mm: 5
Distance from the Heel Point, mm: 5

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*25.09*	**75**	*20.25*	**150**	-	**225**	*19.60*	**300**	*25.60*
5	*25.03*	**80**	*19.53*	**155**	-	**230**	*18.94*	**305**	*26.39*
10	*25.62*	**85**	*19.00*	**160**	-	**235**	*18.36*	**310**	*27.52*
15	*26.00*	**90**	*18.42*	**165**	*31.60*	**240**	*18.24*	**315**	*28.17*
20	*26.71*	**95**	*18.21*	**170**	*40.70*	**245**	*18.20*	**320**	*28.80*
25	*27.38*	**100**	*18.00*	**175**	*42.70*	**250**	*18.48*	**325**	*28.79*
30	*26.68*	**105**	*17.65*	**180**	*42.35*	**255**	*18.75*	**330**	*28.29*
35	*26.50*	**110**	*17.55*	**185**	*42.35*	**260**	*18.97*	**335**	*27.22*
40	*25.70*	**115**	*17.40*	**190**	*42.65*	**265**	*19.52*	**340**	*26.41*
45	*25.10*	**120**	*17.62*	**195**	*42.65*	**270**	*20.04*	**345**	*25.93*
50	*23.75*	**125**	*17.66*	**200**	*34.16*	**275**	*23.23*	**350**	*25.50*
55	*23.10*	**130**	*18.23*	**205**	-	**280**	*21.74*	**355**	*25.24*
60	*22.14*	**135**	*18.80*	**210**	-	**285**	*22.87*	**360**	*25.27*
65	*21.50*	**140**	*19,47*	**215**	-	**290**	*23.60*		
70	*20.90*	**145**	-	**220**	-	**295**	*24.75*		
						Cone Top Plane		**170°**	*40.70*
						Cone Top Plane		**195°**	*42.65*
						Featherline		**325°**	*28.79*

Cross-Section Number: 4
Step of measurement, mm: 5
Distance from the Heel Point, mm: 10

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*25.36*	**75**	*25.11*	**150**	-	**225**	*22.19*	**300**	*31.81*
5	*25.50*	**80**	*24.25*	**155**	-	**230**	*21.61*	**305**	*32.72*
10	*25.63*	**85**	*23.64*	**160**	-	**235**	*21.11*	**310**	*33.17*
15	*25.82*	**90**	*22.93*	**165**	*35.96*	**240**	*21.30*	**315**	*32.72*
20	*26.31*	**95**	*22.26*	**170**	*43.05*	**245**	*21.10*	**320**	*30.42*
25	*26.78*	**100**	*19.35*	**175**	*42/83*	**250**	*21.40*	**325**	*29.47*
30	*27.90*	**105**	*20.70*	**180**	*42.33*	**255**	*21.70*	**330**	*27.83*
35	*29.18*	**110**	*20.33*	**185**	*42.69*	**260**	*22.48*	**335**	*27.05*
40	*30.92*	**115**	*20.30*	**190**	*43.02*	**265**	*23.48*	**340**	*26.49*
45	*30.12*	**120**	*20.17*	**195**	*43.43*	**270**	*24.45*	**345**	*30.61*
50	*49.96*	**125**	*20.24*	**200**	*36.70*	**275**	*25.44*	**350**	*25.80*
55	*54.88*	**130**	*18.64*	**205**	*32.70*	**280**	*27.26*	**355**	*25.54*
60	*27.23*	**135**	*21.11*	**210**	-	**285**	*28.50*	**360**	*25.51*
65	*26.44*	**140**	*19.79*	**215**	-	**290**	*29.61*		
70	*25.78*	**145**	-	**220**	*22.43*	**295**	*30.47*		
						Featherline		**40°84'**	*33.69*
						Cone Top Plane		**169°20'**	*40.92*
						Profile		**182°38'**	*42.63*
						Featherline		**313°36'**	*32.97*

Cross-Section Number: 5
Step of measurement, mm: 10
Distance from the Heel Point, mm: 20

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*24.42*	**75**	*26.74*	**150**	-	**225**	-	**300**	*33.91*
5	*24.12*	**80**	*26.03*	**155**	-	**230**	-	**305**	*34.72*
10	*24.43*	**85**	*25.41*	**160**	-	**235**	*21.96*	**310**	*33.84*
15	*26.18*	**90**	*24.31*	**165**	-	**240**	*22.09*	**315**	*33.17*
20	*26.52*	**95**	*23.65*	**170**	*43.20*	**245**	*22.24*	**320**	*31.09*
25	*26.97*	**100**	*22.71*	**175**	*42.89*	**250**	*22.43*	**325**	*29.55*
30	*27.82*	**105**	*22.18*	**180**	*42.88*	**255**	*23.11*	**330**	*28.32*
35	*28.74*	**110**	*21.69*	**185**	*43.23*	**260**	*23.86*	**335**	*27.60*
40	*31.01*	**115**	*21.45*	**190**	*42.90*	**265**	*25.05*	**340**	*25.55*
45	*31.30*	**120**	*21.30*	**195**	*43.68*	**270**	*26.28*	**345**	*25.04*
50	*30.38*	**125**	*21/13*	**200**	*32.76*	**275**	*27.68*	**350**	*24.38*
55	*29.52*	**130**	*21.44*	**205**	*31.05*	**280**	*29.08*	**355**	*24.29*
60	*28.75*	**135**	-	**210**	-	**285**	*30.36*	**360**	*24.50*
65	*28.08*	**140**	-	**215**	-	**290**	*31.65*		
70	*27.38*	**145**	-	**220**	-	**295**	*32.86*		
						Featherline		**43°95'**	*31.93*
						Cone Top Plane		**168°78'**	*43.38*
						Profile		**181°77'**	*43.06*
						Cone Top Plane		**195°**	*43.68*
						Featherline		**310°**	*33.84*

Cross-Section Number: 6
Step of measurement, mm: 5
Distance from the Heel Point, mm: 25

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*24.01*	**75**	*27.45*	**150**	-	**225**	-	**300**	*35.65*
5	*24.20*	**80**	*26.76*	**155**	-	**230**	*23.53*	**305**	*35.81*
10	*24.18*	**85**	*25.97*	**160**	-	**235**	*23.11*	**310**	*35.20*
15	*24.61*	**90**	*25.02*	**165**	-	**240**	*23.05*	**315**	*32.93*
20	*25.06*	**95**	*24.11*	**170**	*43.90*	**245**	*23.25*	**320**	*31.36*
25	*26.93*	**100**	*23.42*	**175**	*44.08*	**250**	*23.70*	**325**	*29.60*
30	*27.69*	**105**	*22.67*	**180**	*43.12*	**255**	*24.28*	**330**	*28.55*
35	*28.94*	**110**	*22.34*	**185**	*43.16*	**260**	*25.21*	**335**	*26.26*
40	*30.44*	**115**	*22.01*	**190**	*43.76*	**265**	*26.34*	**340**	*25.52*
45	*32.00*	**120**	*21.93*	**195**	*44.50*	**270**	*27.70*	**345**	*25.00*
50	*30.79*	**125**	*21.95*	**200**	*39.44*	**275**	*29.18*	**350**	*24.43*
55	*30.74*	**130**	*22.16*	**205**	*35.31*	**280**	*30.80*	**355**	*25.11*
60	*30.05*	**135**	-	**210**	-	**285**	*32.39*	**360**	*23.34*
65	*30.04*	**140**	-	**215**	-	**290**	*33.47*		
70	*27.87*	**145**	-	**220**	-	**295**	*34.63*		
						Featherline		**43°90'**	*31.93*
						Cone Top Plane		**167°26'**	*43.80*
						Cone Top Plane		**195°**	*44.50*
						Featherline		**309°36'**	*35.53*

Cross-Section Number: 7
Step of measurement, mm: 5
Distance from the Heel Point, mm: 30

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*24.34*	**75**	*28.04*	**150**	*27.24*	**225**	*24.79*	**300**	*36.40*
5	*23.83*	**80**	*27.45*	**155**	*30.16*	**230**	*24.08*	**305**	*36.03*
10	*24.18*	**85**	*26.69*	**160**	*33.71*	**235**	*23.80*	**310**	*35.17*
15	*24.47*	**90**	*25.84*	**165**	*71.08*	**240**	*23.78*	**315**	*32.85*
20	*26.35*	**95**	*24.30*	**170**	*43.57*	**245**	*23.97*	**320**	*31.03*
25	*26.89*	**100**	*24.09*	**175**	*43.26*	**250**	*24.26*	**325**	*29.67*
30	*26.67*	**105**	*23.51*	**180**	*42.80*	**255**	*25.20*	**330**	*28.54*
35	*28.97*	**110**	*22.95*	**185**	*42.58*	**260**	*26.18*	**335**	*26.16*
40	*30.39*	**115**	*22.65*	**190**	*43.77*	**265**	*27.40*	**340**	*25.31*
45	*31.33*	**120**	*22.50*	**195**	*44.28*	**270**	*28.74*	**345**	*23.43*
50	*31.18*	**125**	*22.52*	**200**	*40.67*	**275**	*30.31*	**350**	*24.02*
55	*30.33*	**130**	*22.62*	**205**	*35.01*	**280**	*31.85*	**355**	*24.28*
60	*29.75*	**135**	*23.10*	**210**	*30.56*	**285**	*33.33*	**360**	*24.35*
65	*29.08*	**140**	*23.83*	**215**	*27.87*	**290**	*34.40*		
70	*28.62*	**145**	*25.20*	**220**	*25.60*	**295**	*35.60*		
						Featherline		**44°63'**	*31.89*
						Cone Top Plane		**167°93'**	*43.30*
						Cone Top Plane		**195°86'**	*44.08*
						Featherline		**307°67'**	*36.00*

Cross-Section Number: 8
Step of measurement, mm: 5
Distance from the Heel Point, mm: 35

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*23.58*	**75**	*28.21*	**150**	*27.72*	**225**	*25.36*	**300**	*37.15*
5	*23.76*	**80**	*27.51*	**155**	*30.16*	**230**	*24.58*	**305**	*36.24*
10	*23.94*	**85**	*26.97*	**160**	*34.22*	**235**	*24.27*	**310**	*35.11*
15	*24.25*	**90**	*26.25*	**165**	*40.54*	**240**	*24.31*	**315**	*32.56*
20	*26.12*	**95**	*25.47*	**170**	*43.27*	**245**	*24.52*	**320**	*30.65*
25	*26.50*	**100**	*24.59*	**175**	*43.13*	**250**	*25.01*	**325**	*29.48*
30	*27.21*	**105**	*23.94*	**180**	*42.70*	**255**	*25.81*	**330**	*26.92*
35	*34.14*	**110**	*23.47*	**185**	*43.24*	**260**	*26.84*	**335**	*25.90*
40	*29.71*	**115**	*22.92*	**190**	*43.39*	**265**	*28.11*	**340**	*24.76*
45	*33.15*	**120**	*22.85*	**195**	*44.29*	**270**	*29.72*	**345**	*24.07*
50	*30.63*	**125**	*22.84*	**200**	*41.09*	**275**	*31.10*	**350**	*24.57*
55	*30.11*	**130**	*23.06*	**205**	*35.48*	**280**	*32.55*	**355**	*23.90*
60	*29.53*	**135**	*23.57*	**210**	*31.31*	**285**	*34.24*	**360**	*23.83*
65	*29.23*	**140**	*24.34*	**215**	*28.45*	**290**	*25.45*		
70	*28.65*	**145**	*25.92*	**220**	*26.69*	**295**	*36.31*		
						Featherline		**45°01'**	*30.95*
						Cone Top Plane		**167°66'**	*44.78*
						Profile		**182°13'**	*42.50*
						Cone Top Plane		**196°48'**	*44.24*
						Featherline		**306°74'**	*36.72*

Cross-Section Number: 9
Step of measurement, mm: 5
Distance from the Heel Point, mm: 40

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*23.51*	**75**	*28.30*	**150**	*27.71*	**225**	*25.61*	**300**	*36.30*
5	*23.41*	**80**	*27.74*	**155**	*30.64*	**230**	*24.91*	**305**	*35.49*
10	*25.55*	**85**	*27.20*	**160**	*33.93*	**235**	*24.48*	**310**	*33.90*
15	*23.80*	**90**	*26.30*	**165**	*40.38*	**240**	*24.49*	**315**	*29.72*
20	*25.69*	**95**	*25.66*	**170**	*43.23*	**245**	*24.83*	**320**	*27.65*
25	*26.08*	**100**	*24.82*	**175**	*42.58*	**250**	*25.43*	**325**	*26.75*
30	*26.63*	**105**	*24.19*	**180**	*42.36*	**255**	*26.23*	**330**	*25.86*
35	*27.82*	**110**	*23.70*	**185**	*42.56*	**260**	*27.26*	**335**	*25.18*
40	*29.35*	**115**	*23.37*	**190**	*43.06*	**265**	*28.58*	**340**	*24.56*
45	*30.64*	**120**	*23.04*	**195**	*44.05*	**270**	*30.18*	**345**	*23.75*
50	*29.83*	**125**	*23.01*	**200**	*41.10*	**275**	*40.61*	**350**	*23.27*
55	*29.59*	**130**	*23.11*	**205**	*36.08*	**280**	*32.47*	**355**	*22.90*
60	*29.31*	**135**	*23.75*	**210**	*31.69*	**285**	*33.67*	**360**	*22.62*
65	*28.93*	**140**	*24.61*	**215**	*28.79*	**290**	*35.16*		
70	*28.48*	**145**	*25.89*	**220**	*26.91*	**295**	*35.74*		
						Featherline		**45°**	*30.61*
						Cone Top Plane		**166°52'**	*43.40*
						Profile		**182°44'**	*42.38*
						Cone Top Plane		**195°**	*44.05*
						Featherline		**310°**	*33.90*

Cross-Section Number: 10
Step of measurement, mm: 5
Distance from the Heel Point, mm: 45

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*22.78*	**75**	*27.36*	**150**	*26.79*	**225**	*26.19*	**300**	*38.14*
5	*22.64*	**80**	*27.35*	**155**	*28.74*	**230**	*25.33*	**305**	*36.92*
10	*24.38*	**85**	*26.32*	**160**	*30.37*	**235**	*24.56*	**310**	*35.10*
15	*18.50*	**90**	*25.80*	**165**	*40.48*	**240**	*24.30*	**315**	*33.02*
20	*24.64*	**95**	*24.79*	**170**	*43.85*	**245**	*24.72*	**320**	*32.46*
25	*28.73*	**100**	*24.20*	**175**	*42.23*	**250**	*25.27*	**325**	*29.27*
30	*25.86*	**105**	*23.29*	**180**	*41.80*	**255**	*26.24*	**330**	*28.39*
35	*26.51*	**110**	*23.91*	**185**	*41.70*	**260**	*27.13*	**335**	*27.18*
40	*28.10*	**115**	*22.72*	**190**	*41.81*	**265**	*28.61*	**340**	*24.59*
45	*28.36*	**120**	*22.63*	**195**	*43.12*	**270**	*30.12*	**345**	*23.84*
50	*28.30*	**125**	*22.70*	**200**	*42.44*	**275**	*31.91*	**350**	*23.59*
55	*28.13*	**130**	*22.44*	**205**	*37.36*	**280**	*33.07*	**355**	*23.35*
60	*27.97*	**135**	*22.66*	**210**	*32.25*	**285**	*34.99*	**360**	*23.13*
65	*27.82*	**140**	*23.71*	**215**	*27.09*	**290**	*26.57*		
70	*28.56*	**145**	*24.70*	**220**	*26.76*	**295**	*28.30*		
						Featherline		**45°**	*28.36*
						Cone Top Plane		**167°75'**	*42.69*
						Profile		**177°92'**	*41.56*

Cross-Section Number: **11**
Step of measurement, mm: **5**
Distance from the Heel Point, mm: **50**

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*24.30*	**75**	*27.49*	**150**	*27.74*	**225**	*26.73*	**300**	*38.60*
5	*24.13*	**80**	*27.22*	**155**	*30.18*	**230**	*25.74*	**305**	*38.03*
10	*23.93*	**85**	*26.76*	**160**	*35.06*	**235**	*25.43*	**310**	*35.05*
15	*24.12*	**90**	*26.17*	**165**	*41.19*	**240**	*25.26*	**315**	*32.68*
20	*24.30*	**95**	*25.56*	**170**	*43.13*	**245**	*25.51*	**320**	*30.45*
25	*24.85*	**100**	*24.75*	**175**	*42.50*	**250**	*25.90*	**325**	*29.08*
30	*25.68*	**105**	*24.30*	**180**	*42.25*	**255**	*26.73*	**330**	*28.21*
35	*26.66*	**110**	*24.05*	**185**	*42.54*	**260**	*27.92*	**335**	*27.01*
40	*28.08*	**115**	*23.50*	**190**	*42.75*	**265**	*29.33*	**340**	*26.18*
45	*28.12*	**120**	*23.34*	**195**	*43.54*	**270**	*31.04*	**345**	*25.31*
50	*27.98*	**125**	*23.37*	**200**	*43.43*	**275**	*32.66*	**350**	*24.82*
55	*27.81*	**130**	*23.45*	**205**	*37.58*	**280**	*34.27*	**355**	*24.51*
60	*27.73*	**135**	*23.92*	**210**	*31.95*	**285**	*35.76*	**360**	*24.35*
65	*27.68*	**140**	*24.52*	**215**	*29.84*	**290**	*37.07*		
70	*27.40*	**145**	*26.18*	**220**	*28.25*	**295**	*38.02*		
						Featherline		**43°12'**	*28.00*
						Cone Top Plane		**167°78'**	*43.42*
						Cone Top Plane		**198°93'**	*44.47*
						Featherline		**303°75'**	*37.48*

Cross-Section Number: **12**
Step of measurement, mm: **5**
Distance from the Heel Point, mm: **55**

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*24.04*	**75**	*27.35*	**150**	*27.51*	**225**	*27.39*	**300**	*39.05*
5	*23.82*	**80**	*27.24*	**155**	*28.80*	**230**	*26.44*	**305**	*38.15*
10	*23.70*	**85**	*26.84*	**160**	*31.65*	**235**	*25.68*	**310**	*35.70*
15	*23.80*	**90**	*26.42*	**165**	*37.24*	**240**	*25.59*	**315**	*33.42*
20	*24.09*	**95**	*25.85*	**170**	*42.02*	**245**	*25.63*	**320**	*31.02*
25	*24.50*	**100**	*25.38*	**175**	*41.76*	**250**	*26.05*	**325**	*29.74*
30	*25.13*	**105**	*24.52*	**180**	*41.74*	**255**	*26.68*	**330**	*28.24*
35	*25.84*	**110**	*24.21*	**185**	*42.53*	**260**	*27.81*	**335**	*27.21*
40	*27.12*	**115**	*23.75*	**190**	*43.20*	**265**	*29.15*	**340**	*26.28*
45	*27.18*	**120**	*23.60*	**195**	*44.09*	**270**	*30.64*	**345**	*25.61*
50	*27.20*	**125**	*23.49*	**200**	*44.40*	**275**	*32.54*	**350**	*24.92*
55	*27.18*	**130**	*23.64*	**205**	*39.13*	**280**	*34.41*	**355**	*24.53*
60	*27.13*	**135**	*23.91*	**210**	*34.04*	**285**	*36.02*	**360**	*24.15*
65	*27.15*	**140**	*24.87*	**215**	*30.87*	**290**	*37.36*		
70	*27.13*	**145**	*25.60*	**220**	*28.45*	**295**	*38.18*		
						Featherline		**43°25'**	*27.71*
						Cone Top Plane		**168°63'**	*42.13*
						Cone Top Plane		**201°19**	*44.30*
						Featherline		**305°**	*38.15*

Cross-Section Number: 13
Step of measurement, mm: 5
Distance from the Heel Point, mm: 60

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*24.11*	**75**	*26.90*	**150**	*26.74*	**225**	*27.85*	**300**	*39.45*
5	*23.70*	**80**	*26.95*	**155**	*28.63*	**230**	*26.67*	**305**	*38.58*
10	*23.51*	**85**	*26.79*	**160**	*31.37*	**235**	*26.20*	**310**	*36.73*
15	*23.50*	**90**	*26.45*	**165**	*34.85*	**240**	*25.70*	**315**	*34.17*
20	*23.69*	**95**	*26.90*	**170**	*41.21*	**245**	*27.05*	**320**	*31.65*
25	*24.26*	**100**	*25.59*	**175**	*47.35*	**250**	*26.02*	**325**	*30.31*
30	*24.95*	**105**	*24.94*	**180**	*46.77*	**255**	*34.90*	**330**	*28.68*
35	*25.77*	**110**	*24.33*	**185**	*46.80*	**260**	*27.62*	**335**	*27.45*
40	*26.64*	**115**	*24.00*	**190**	*46.85*	**265**	*28.85*	**340**	*29.60*
45	*26.37*	**120**	*23.66*	**195**	*47.36*	**270**	*30.40*	**345**	*25.72*
50	*26.40*	**125**	*23.60*	**200**	*47.64*	**275**	*32.39*	**350**	*25.08*
55	*26.37*	**130**	*23.71*	**205**	*40.70*	**280**	*34.47*	**355**	*24.59*
60	*26.45*	**135**	*24.02*	**210**	*35.35*	**285**	*36.25*	**360**	*24.15*
65	*26.56*	**140**	*24.73*	**215**	*31.90*	**290**	*37.53*		
70	*26.67*	**145**	*25.69*	**220**	*29.38*	**295**	*38.64*		
						Featherline		**42°62'**	*26.05*
						Cone Top Plane		**172°74'**	*47.32*
						Cone Top Plane		**200°55'**	*47.55*
						Featherline		**305°**	*38.58*

Cross-Section Number: 14
Step of measurement, mm: 5
Distance from the Heel Point, mm: 65

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*23.85*	**75**	*26.12*	**150**	*26.76*	**225**	*27.71*	**300**	*39.81*
5	*23.89*	**80**	*26.19*	**155**	*29.71*	**230**	*26.65*	**305**	*39.12*
10	*23.35*	**85**	*26.17*	**160**	*31.04*	**235**	*25.98*	**310**	*37.24*
15	*23.43*	**90**	*25.85*	**165**	*35.42*	**240**	*25.81*	**315**	*33.52*
20	*23.81*	**95**	*25.40*	**170**	*42.21*	**245**	*25.73*	**320**	*31.64*
25	*24.15*	**100**	*24.82*	**175**	*48.78*	**250**	*25.68*	**325**	*30.21*
30	*24.74*	**105**	*24.69*	**180**	*48.26*	**255**	*26.43*	**330**	*29.97*
35	*25.27*	**110**	*24.25*	**185**	*48.45*	**260**	*27.25*	**335**	*27.54*
40	*24.68*	**115**	*23.73*	**190**	*48.76*	**265**	*28.50*	**340**	*26.64*
45	*25.13*	**120**	*23.51*	**195**	*48.65*	**270**	*30.37*	**345**	*25.64*
50	*25.28*	**125**	*23.37*	**200**	*48.19*	**275**	*32.50*	**350**	*24.98*
55	*25.35*	**130**	*23.50*	**205**	*40.14*	**280**	*34.55*	**355**	*24.33*
60	*25,63*	**135**	*23.74*	**210**	*34.99*	**285**	*36.40*	**360**	*23.73*
65	*25.75*	**140**	*24.50*	**215**	*31.40*	**290**	*37.52*		
70	*25.00*	**145**	*25.51*	**220**	*29.41*	**295**	*38.80*		
						Featherline		**40°30'**	*25.17*
						Cone Top Plane		**172°51'**	*48.44*
						Cone Top Plane		**200°**	*48.19*
						Featherline		**305°**	*39.12*

Cross-Section Number: 15
Step of measurement, mm: 5
Distance from the Heel Point, mm: 70

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*23.83*	**75**	*26.21*	**150**	*26.91*	**225**	*28.21*	**300**	*40.60*
5	*23.45*	**80**	*26.23*	**155**	*28.87*	**230**	*27.33*	**305**	*40.15*
10	*23.29*	**85**	*26.27*	**160**	*32.95*	**235**	*26.20*	**310**	*38.31*
15	*23.45*	**90**	*25.94*	**165**	*35.85*	**240**	*25.93*	**315**	*34.79*
20	*23.65*	**95**	*25.70*	**170**	*43.07*	**245**	*25.92*	**320**	*32.80*
25	*24.02*	**100**	*25.31*	**175**	*51.76*	**250**	*26.21*	**325**	*30.79*
30	*24.49*	**105**	*24.46*	**180**	*51.12*	**255**	*26.78*	**330**	*29.21*
35	*25.03*	**110**	*24.20*	**185**	*51.23*	**260**	*27.64*	**335**	*28.03*
40	*24.07*	**115**	*23.79*	**190**	*51.37*	**265**	*29.01*	**340**	*26.74*
45	*24.40*	**120**	*23.45*	**195**	*51.96*	**270**	*30.55*	**345**	*25.97*
50	*24.71*	**125**	*23.42*	**200**	*49.59*	**275**	*32.68*	**350**	*25.36*
55	*24.86*	**130**	*23.61*	**205**	*40.71*	**280**	*34.76*	**355**	*24.53*
60	*25.31*	**135**	*23.72*	**210**	*34.85*	**285**	*36.72*	**360**	*24.07*
65	*25.57*	**140**	*24.04*	**215**	*31.99*	**290**	*38.46*		
70	*25.87*	**145**	*25.96*	**220**	*29.41*	**295**	*39.66*		
						Featherline		**37°63'**	*24.10*
						Cone Top Plane		**172°66'**	*50.20*
						Cone Top Plane		**198°34'**	*52.04*
						Featherline		**305°**	*40.15*

Cross-Section Number: 16
Step of measurement, mm: 5
Distance from the Heel Point, mm: 75

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*24.30*	**75**	*26.02*	**150**	*26.74*	**225**	*28.28*	**300**	*41.10*
5	*23.70*	**80**	*26.17*	**155**	*28.39*	**230**	*27.28*	**305**	*40.80*
10	*23.56*	**85**	*26.14*	**160**	*30.96*	**235**	*26.65*	**310**	*38.83*
15	*23.70*	**90**	*26.06*	**165**	*34.27*	**240**	*26.16*	**315**	*35.45*
20	*23.90*	**95**	*25.62*	**170**	*29.46*	**245**	*25.99*	**320**	*33.41*
25	*24.15*	**100**	*25.25*	**175**	*53.68*	**250**	*26.14*	**325**	*31.44*
30	*24.45*	**105**	*25.24*	**180**	*53.50*	**255**	*26.61*	**330**	*29.80*
35	*23.46*	**110**	*24.11*	**185**	*53.37*	**260**	*27.66*	**335**	*28.51*
40	*23.63*	**115**	*24.71*	**190**	*53.52*	**265**	*28.76*	**340**	*27.26*
45	*23.91*	**120**	*23.51*	**195**	*54.34*	**270**	*30.27*	**345**	*26.27*
50	*24.98*	**125**	*23.45*	**200**	*48.05*	**275**	*32.35*	**350**	*25.50*
55	*24.61*	**130**	*23.60*	**205**	*40,54*	**280**	*34.91*	**355**	*24.70*
60	*24.98*	**135**	*23.97*	**210**	*35.70*	**285**	*37.11*	**360**	*24.15*
65	*25/31*	**140**	*24.60*	**215**	*32,32*	**290**	*40.15*		
70	*25.70*	**145**	*25.67*	**220**	*30.05*	**295**	*40.26*		
						Featherline		**33°37'**	*24.63*
						Cone Top Plane		**172°84'**	*54.11*
						Cone Top Plane		**197°01'**	*54.71*
						Featherline		**305°**	*40.80*

Cross-Section Number: 17
Step of measurement, mm: 5
Distance from the Heel Point, mm: 80

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*24.53*	**75**	*25.89*	**150**	*26.61*	**225**	*28.43*	**300**	*41.87*
5	*24.25*	**80**	*26.06*	**155**	*28.38*	**230**	*27.23*	**305**	*42.21*
10	*24.20*	**85**	*26.12*	**160**	*31.11*	**235**	*26.58*	**310**	*40.57*
15	*24.08*	**90**	*25.90*	**165**	*35.65*	**240**	*26.22*	**315**	*37.25*
20	*24.17*	**95**	*25.61*	**170**	*42.36*	**245**	*26.01*	**320**	*34/64*
25	*24.35*	**100**	*25.19*	**175**	*56.58*	**250**	*26.11*	**325**	*32.51*
30	*24.60*	**105**	*24,68*	**180**	*56.30*	**255**	*26.58*	**330**	*30.56*
35	*23.59*	**110**	*24.20*	**185**	*56.29*	**260**	*27.50*	**335**	*29.15*
40	*23.82*	**115**	*23.80*	**190**	*56.59*	**265**	*28.73*	**340**	*27.78*
45	*24.12*	**120**	*23.50*	**195**	*57.40*	**270**	*30.38*	**345**	*26.71*
50	*24.15*	**125**	*23.38*	**200**	*46.48*	**275**	*32.59*	**350**	*26.02*
55	*24,51*	**130**	*23.15*	**205**	*40.84*	**280**	*34.92*	**355**	*25.29*
60	*25.02*	**135**	*23.61*	**210**	*35.82*	**285**	*37.34*	**360**	*24.63*
65	*25.42*	**140**	*24.18*	**215**	*34.17*	**290**	*39.26*		
70	*25.74*	**145**	*25.31*	**220**	*30.25*	**295**	*40.86*		
						Featherline		**30°82'**	*24.64*
						Cone Top Plane		**174°65'**	*56.56*
						Cone Top Plane		**195°45'**	*54.24*
						Featherline		**306°54'**	*41.91*

Cross-Section Number: 18
Step of measurement, mm: 5
Distance from the Heel Point, mm: 85

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*25.64*	**75**	*26.00*	**150**	*25.45*	**225**	*29.78*	**300**	*41.76*
5	*25.26*	**80**	*26.15*	**155**	*26.88*	**230**	*28.30*	**305**	*42.95*
10	*24.85*	**85**	*16.22*	**160**	*28.89*	**235**	*27.32*	**310**	*43.09*
15	*24.78*	**90**	*25.78*	**165**	*31.59*	**240**	*26.47*	**315**	*41.20*
20	*24.62*	**95**	*25.66*	**170**	*35.81*	**245**	*25.76*	**320**	*37.86*
25	*25.56*	**100**	*25.54*	**175**	*44.58*	**250**	*26.06*	**325**	*34.87*
30	*24/65*	**105**	*24.95*	**180**	*58.95*	**255**	*26.14*	**330**	*32,76*
35	*23.80*	**110**	*24.26*	**185**	*59.19*	**260**	*26.67*	**335**	*30.61*
40	*24.10*	**115**	*23.84*	**190**	*58.96*	**265**	*27.63*	**340**	*29.41*
45	*24.23*	**120**	*23.56*	**195**	*59.63*	**270**	*28.95*	**345**	*27.99*
50	*24.36*	**125**	*23.32*	**200**	*55.40*	**275**	*30.74*	**350**	*27.18*
55	*24.51*	**130**	*23.12*	**205**	*45.53*	**280**	*33.10*	**355**	*26.33*
60	*25.01*	**135**	*23.65*	**210**	*39.26*	**285**	*35.65*	**360**	*25.48*
65	*25.22*	**140**	*23.98*	**215**	*35.21*	**290**	*38.15*		
70	*25.54*	**145**	*24.58*	**220**	*32.07*	**295**	*40.14*		
						Featherline		**30°68'**	*24.67*
						Cone Top Plane		**179°23'**	*59.11*
						Cone Top Plane		**197°75'**	*59.72*
						Featherline		**310°94'**	*42.80*

Cross-Section Number: 19
Step of measurement, mm: 10
Distance from the Heel Point, mm: 95

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*27.19*	**75**	*26.47*	**150**	*26.51*	**225**	*28.07*	**300**	*44.88*
5	*26.86*	**80**	*26.20*	**155**	*28.72*	**230**	*26.79*	**305**	*45.73*
10	*26.52*	**85**	*26.05*	**160**	*31.27*	**235**	*26.19*	**310**	*44.30*
15	*26.30*	**90**	*25.71*	**165**	*35.91*	**240**	*25.80*	**315**	*41.13*
20	*25.17*	**95**	*24.92*	**170**	*42.20*	**245**	*25.73*	**320**	*38.22*
25	*25.19*	**100**	*24.37*	**175**	*53.70*	**250**	*25.75*	**325**	*35.90*
30	*25.30*	**105**	*23.56*	**180**	*63.59*	**255**	*26.15*	**330**	*33.61*
35	*25.37*	**110**	*23.34*	**185**	*63.70*	**260**	*27.01*	**335**	*32.02*
40	*25.47*	**115**	*23.09*	**190**	*63.44*	**265**	*28.29*	**340**	*30.64*
45	*25.57*	**120**	*22.90*	**195**	*63.57*	**270**	*29.97*	**345**	*29.52*
50	*25.81*	**125**	*22.85*	**200**	*45.04*	**275**	*32.11*	**350**	*28.65*
55	*26.00*	**130**	*23.23*	**205**	*38.82*	**280**	*35.16*	**355**	*28.77*
60	*26.24*	**135**	*23.29*	**210**	*34.92*	**285**	*38.16*	**360**	*27.31*
65	*26.34*	**140**	*24.14*	**215**	*31.91*	**290**	*40.92*		
70	*26.42*	**145**	*25.04*	**220**	*29.89*	**295**	*43.15*		
						Featherline		**19°93'**	*26.24*
						Cone Top Plane		**176°85'**	*63.06*
						Cone Top Plane		**190°**	*63.44*
						Featherline		**307°87'**	*45.94*

Cross-Section Number: 20
Step of measurement, mm: 5
Distance from the Heel Point, mm: 100

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*29.11*	**75**	*26.81*	**150**	*25.07*	**225**	*29.40*	**300**	*44.25*
5	*28.45*	**80**	*26.61*	**155**	*26.60*	**230**	*27.83*	**305**	*46.06*
10	*28.04*	**85**	*26.42*	**160**	*28.56*	**235**	*26.60*	**310**	*47.37*
15	*27.51*	**90**	*25.85*	**165**	*31.75*	**240**	*25.86*	**315**	*46.24*
20	*27.11*	**95**	*25.18*	**170**	*36.12*	**245**	*25.11*	**320**	*42.88*
25	*26.10*	**100**	*24.45*	**175**	*44.43*	**250**	*25.12*	**325**	*39.60*
30	*26.16*	**105**	*23.89*	**180**	*53,71*	**255**	*25.64*	**330**	*37.16*
35	*26.26*	**110**	*23.43*	**185**	*65.65*	**260**	*26.09*	**335**	*35.15*
40	*26.31*	**115**	*22.59*	**190**	*66.20*	**265**	*26.90*	**340**	*33.52*
45	*26.45*	**120**	*22.32*	**195**	*60.32*	**270**	*28.11*	**345**	*31.79*
50	*26.40*	**125**	*21.97*	**200**	*49.19*	**275**	*29.77*	**350**	*30.80*
55	*26.67*	**130**	*22.43*	**205**	*43.25*	**280**	*32.05*	**355**	*29.91*
60	*26.80*	**135**	*22.82*	**210**	*38.13*	**285**	*35.05*	**360**	*29.15*
65	*27.00*	**140**	*23.22*	**215**	*34.32*	**290**	*38.30*		
70	*26.89*	**145**	*24.09*	**220**	*29.32*	**295**	*41.76*		
						Featherline		**20°86'**	*27.13*
						Cone Top Plane		**183°57'**	*65.41*
						Cone Top Plane		**192°14'**	*66.00*
						Featherline		**313°18'**	*47.38*

Cross-Section Number: 21
Step of measurement, mm: 5
Distance from the Heel Point, mm: 105

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*30.84*	**75**	*27.87*	**150**	*25.11*	**225**	*29.31*	**300**	*45.05*
5	*30.29*	**80**	*27.84*	**155**	*26.65*	**230**	*27.71*	**305**	*47.53*
10	*29.70*	**85**	*26.70*	**160**	*28.69*	**235**	*26.59*	**310**	*48.92*
15	*29.15*	**90**	*26.08*	**165**	*31.35*	**240**	*25.93*	**315**	*48.38*
20	*27.98*	**95**	*25.34*	**170**	*35.29*	**245**	*25.54*	**320**	*35.09*
25	*27.87*	**100**	*24.27*	**175**	*41.21*	**250**	*25.16*	**325**	*41.83*
30	*27.77*	**105**	*23.38*	**180**	*54.37*	**255**	*25.32*	**330**	*39.26*
35	*27.81*	**110**	*23.19*	**185**	*63.29*	**260**	*26.04*	**335**	*36.72*
40	*27.69*	**115**	*22.79*	**190**	*64.11*	**265**	*26.72*	**340**	*35.36*
45	*27.76*	**120**	*22.38*	**195**	*58.83*	**270**	*27.84*	**345**	*33.75*
50	*27.72*	**125**	*22.50*	**200**	*50.25*	**275**	*29.39*	**350**	*32.63*
55	*27.79*	**130**	*22.59*	**205**	*42.50*	**280**	*31.79*	**355**	*31.61*
60	*27.87*	**135**	*22.54*	**210**	*37.86*	**285**	*35.05*	**360**	*30.69*
65	*27.88*	**140**	*23.21*	**215**	*34.13*	**290**	*38.50*		
70	*27.82*	**145**	*23.74*	**220**	*31.28*	**295**	*42.39*		
						Featherline		**18°67'**	*28.52*
						Featherline		**313°91'**	*48.42*

Cross-Section Number: 22
Step of measurement, mm: 5
Distance from the Heel Point, mm: 110

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*32.71*	**75**	*28.48*	**150**	*24.36*	**225**	*29.13*	**300**	*45.90*
5	*32.16*	**80**	*27.65*	**155**	*26.17*	**230**	*27/43*	**305**	*48.51*
10	*31.16*	**85**	*27.13*	**160**	*28.36*	**235**	*26.37*	**310**	*50.52*
15	*30.98*	**90**	*26.35*	**165**	*31.41*	**240**	*25.71*	**315**	*51.12*
20	*39.81*	**95**	*25.30*	**170**	*25.65*	**245**	*25.22*	**320**	*48.06*
25	*31.66*	**100**	*24.42*	**175**	*41.47*	**250**	*24.61*	**325**	*44.25*
30	*29.45*	**105**	*23.74*	**180**	*51.32*	**255**	*25.40*	**330**	*41.64*
35	*29.35*	**110**	*22.93*	**185**	*59.80*	**260**	*25.61*	**335**	*39.42*
40	*39.32*	**115**	*22.67*	**190**	*60.17*	**265**	*26.45*	**340**	*37.70*
45	*29.32*	**120**	*22.37*	**195**	*55.94*	**270**	*27.41*	**345**	*26.02*
50	*29.45*	**125**	*22.26*	**200**	*48.92*	**275**	*29.32*	**350**	*34.76*
55	*29.26*	**130**	*22.34*	**205**	*42.49*	**280**	*31.25*	**355**	*33.65*
60	*29.09*	**135**	*22.58*	**210**	*37.50*	**285**	*34.36*	**360**	*32.81*
65	*29.09*	**140**	*23.19*	**215**	*33.63*	**290**	*37.94*		
70	*28.72*	**145**	*23.69*	**220**	*30.73*	**295**	*42.17*		
						Featherline		**15°19'**	*31.11*
						Featherline		**314°90'**	*51.18*

Cross-Section Number: 23
Step of measurement, mm: 5
Distance from the Heel Point, mm: 115

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*34.97*	**75**	*26.06*	**150**	*24.40*	**225**	*28.82*	**300**	*46.51*
5	*34.42*	**80**	*28.24*	**155**	*26.01*	**230**	*27.38*	**305**	*49.71*
10	*33.87*	**85**	*27.20*	**160**	*27.87*	**235**	*26.31*	**310**	*52.06*
15	*32.13*	**90**	*26.26*	**165**	*31.19*	**240**	*25.40*	**315**	*52.62*
20	*31.82*	**95**	*25.29*	**170**	*34.79*	**245**	*24.99*	**320**	*50.21*
25	*31.71*	**100**	*24.30*	**175**	*40.57*	**250**	*24.80*	**325**	*56.83*
30	*31.47*	**105**	*23.40*	**180**	*48.82*	**255**	*25.06*	**330**	*44.13*
35	*31.47*	**110**	*22.86*	**185**	*56.10*	**260**	*25.73*	**335**	*41.81*
40	*31.33*	**115**	*22.43*	**190**	*56.90*	**265**	*26.19*	**340**	*39.79*
45	*31.31*	**120**	*22.09*	**195**	*53.58*	**270**	*27.02*	**345**	*38.27*
50	*30.97*	**125**	*22.08*	**200**	*47.43*	**275**	*28.51*	**350**	*37.02*
55	*30.83*	**130**	*22.09*	**205**	*41.01*	**280**	*30.76*	**355**	*35.87*
60	*30.41*	**135**	*21.61*	**210**	*36.70*	**285**	*33.83*	**360**	*35.02*
65	*30.22*	**140**	*22.63*	**215**	*33.20*	**290**	*37.76*		
70	*29.73*	**145**	*23.41*	**220**	*30.71*	**295**	*42.27*		
						Featherline		**14°67'**	*32.53*
						Featherline		**315°43'**	*53.22*

Cross-Section Number: 24
Step of measurement, mm: 5
Distance from the Heel Point, mm: 120

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*36.87*	**75**	*29.52*	**150**	*24.40*	**225**	*27.79*	**300**	*47.33*
5	*36.47*	**80**	*28.41*	**155**	*25.86*	**230**	*26.71*	**305**	*50.97*
10	*36.02*	**85**	*27.31*	**160**	*28.13*	**235**	*25.73*	**310**	*53.62*
15	*34.25*	**90**	*26.18*	**165**	*31.30*	**240**	*25.16*	**315**	*54.69*
20	*33.96*	**95**	*24.79*	**170**	*35.02*	**245**	*24.64*	**320**	*52.44*
25	*33.74*	**100**	*23.97*	**175**	*40.72*	**250**	*24.47*	**325**	*49.27*
30	*33.61*	**105**	*23.35*	**180**	*48.12*	**255**	*24.69*	**330**	*46.31*
35	*33.24*	**110**	*22.72*	**185**	*52.67*	**260**	*25.12*	**335**	*44.03*
40	*33.31*	**115**	*22.14*	**190**	*53.32*	**265**	*25.85*	**340**	*41.96*
45	*33.07*	**120**	*21.85*	**195**	*49.94*	**270**	*26.76*	**345**	*40.37*
50	*32.76*	**125**	*21.75*	**200**	*45.14*	**275**	*28.29*	**350**	*39.06*
55	*32.51*	**130**	*21.85*	**205**	*39.36*	**280**	*30.51*	**355**	*37.90*
60	*31.97*	**135**	*22.03*	**210**	*35.39*	**285**	*33.82*	**360**	*37.13*
65	*31.95*	**140**	*22.43*	**215**	*32.10*	**290**	*27.51*		
70	*30.36*	**145**	*23.23*	**220**	*29.82*	**295**	*42.81*		
						Featherline		**14°55'**	*35.48*
						Featherline		**316°04**	*54.71*

Cross-Section Number: 25
Step of measurement, mm: 5
Distance from the Heel Point, mm: 125

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*39.61*	**75**	*30.06*	**150**	*24.02*	**225**	*27.37*	**300**	*47.89*
5	*39.06*	**80**	*28.63*	**155**	*25.71*	**230**	*26.21*	**305**	*52.08*
10	*38.42*	**85**	*27.29*	**160**	*27.72*	**235**	*25.37*	**310**	*55.02*
15	*37.32*	**90**	*25.90*	**165**	*35.90*	**240**	*26.64*	**315**	*57.00*
20	*36.19*	**95**	*24.72*	**170**	*34.54*	**245**	*24.27*	**320**	*55.27*
25	*36.30*	**100**	*23.68*	**175**	*39.41*	**250**	*24.11*	**325**	*55.43*
30	*35.61*	**105**	*22.74*	**180**	*45.32*	**255**	*24.26*	**330**	*39.05*
35	*35.70*	**110**	*22.13*	**185**	*48.61*	**260**	*24.79*	**335**	*46.37*
40	*35.51*	**115**	*21.84*	**190**	*49.30*	**265**	*25.55*	**340**	*44.34*
45	*34.97*	**120**	*21.66*	**195**	*46.90*	**270**	*26.28*	**345**	*42.67*
50	*36.64*	**125**	*21.64*	**200**	*42.50*	**275**	*27.69*	**350**	*41.55*
55	*33.85*	**130**	*21.62*	**205**	*37.84*	**280**	*28.80*	**355**	*40.44*
60	*23.39*	**135**	*27.62*	**210**	*34.26*	**285**	*32.64*	**360**	*39.52*
65	*32.40*	**140**	*22.19*	**215**	*37.38*	**290**	*37.38*		
70	*31.30*	**145**	*23.03*	**220**	*42.75*	**295**	*42.75*		
						Featherline		**14°98'**	*38.03*
						Featherline		**316°89'**	*57.55*

Cross-Section Number: 26
Step of measurement, mm: 10
Distance from the Heel Point, mm: 135

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*43.88*	**75**	*30.47*	**150**	*23.31*	**225**	*25.53*	**300**	*48.17*
5	*43.59*	**80**	*28.59*	**155**	*24.68*	**230**	*24.38*	**305**	*53.47*
10	*43.17*	**85**	*27.91*	**160**	*26.69*	**235**	*23.68*	**310**	*57.80*
15	*43.00*	**90**	*25.19*	**165**	*28.89*	**240**	*23.16*	**315**	*60.45*
20	*41.58*	**95**	*24.13*	**170**	*31.73*	**245**	*22.76*	**320**	*59.90*
25	*41.25*	**100**	*22.83*	**175**	*35.17*	**250**	*22.77*	**325**	*56.86*
30	*41.04*	**105**	*22.28*	**180**	*37.99*	**255**	*22.91*	**330**	*54.21*
35	*40.71*	**110**	*21.37*	**185**	*40.22*	**260**	*23.37*	**335**	*51.25*
40	*40.15*	**115**	*21.24*	**190**	*20.43*	**265**	*24.28*	**340**	*49.22*
45	*39.49*	**120**	*20.78*	**195**	*39.41*	**270**	*25.02*	**345**	*47.76*
50	*38.31*	**125**	*20.65*	**200**	*36.82*	**275**	*26.25*	**350**	*46.31*
55	*37.29*	**130**	*20.52*	**205**	*33.78*	**280**	*28.32*	**355**	*44.94*
60	*35.92*	**135**	*21.99*	**210**	*31.03*	**285**	*31.33*	**360**	*44.16*
65	*34.31*	**140**	*21.57*	**215**	*28.66*	**290**	*35.85*		
70	*32.53*	**145**	*22.34*	**220**	*26.83*	**295**	*42.39*		
						Featherline		**19°48'**	*42.88*
						Featherline		**317°82'**	*61.50*

Cross-Section Number: 27
Step of measurement, mm: 5
Distance from the Heel Point, mm: 140

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*46.32*	**75**	*30.99*	**150**	*22.62*	**225**	*24.23*	**300**	*48.69*
5	*46.05*	**80**	*38.87*	**155**	*23.85*	**230**	*24.43*	**305**	*53.54*
10	*45.66*	**85**	*26.62*	**160**	*25.21*	**235**	*22.72*	**310**	*58.40*
15	*45.60*	**90**	*25.00*	**165**	*27.29*	**240**	*22.35*	**315**	*61.75*
20	*45.57*	**95**	*23.76*	**170**	*29.75*	**245**	*21.90*	**320**	*60.79*
25	*44.18*	**100**	*22.70*	**175**	*32.14*	**250**	*21.99*	**325**	*58.02*
30	*43.94*	**105**	*21.83*	**180**	*34.40*	**255**	*22.03*	**330**	*53.75*
35	*43.48*	**110**	*21.15*	**185**	*35.75*	**260**	*22.50*	**335**	*41.35*
40	*42.74*	**115**	*20.69*	**190**	*35.87*	**265**	*23.22*	**340**	*49.47*
45	*41.84*	**120**	*20.37*	**195**	*35.40*	**270**	*24.21*	**345**	*49.65*
50	*40.57*	**125**	*20.31*	**200**	*33.49*	**275**	*25.82*	**350**	*48.05*
55	*38.99*	**130**	*20.20*	**205**	*31.39*	**280**	*27439*	**355**	*47.25*
60	*37.38*	**135**	*20.57*	**210**	*28.99*	**285**	*30.73*	**360**	*46.45*
65	*35.09*	**140**	*20.86*	**215**	*27.09*	**290**	*35.75*		
70	*33.33*	**145**	*21.71*	**220**	*25.43*	**295**	*41.82*		
						Featherline		**23°76'**	*45.04*
						Featherline		**317°31'**	*62.63*

Cross-Section Number: 28
Step of measurement, mm: 5
Distance from the Heel Point, mm: 145

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*47.80*	**75**	*33.12*	**150**	*21.39*	**225**	*22.50*	**300**	*49.00*
5	*46.48*	**80**	*28.26*	**155**	*22.55*	**230**	*21.78*	**305**	*54.03*
10	*47.48*	**85**	*26.65*	**160**	*23.67*	**235**	*21.20*	**310**	*58.80*
15	*47.91*	**90**	*24.23*	**165**	*25.28*	**240**	*20.81*	**315**	*62.34*
20	*48.17*	**95**	*22.59*	**170**	*26.93*	**245**	*20.61*	**320**	*61.18*
25	*48.46*	**100**	*21.78*	**175**	*28.53*	**250**	*20.67*	**325**	*58.40*
30	*46.70*	**105**	*20.48*	**180**	*29.94*	**255**	*20.92*	**330**	*55.73*
35	*46.00*	**110**	*20.34*	**185**	*30.72*	**260**	*21.30*	**335**	*53.66*
40	*45.18*	**115**	*19.97*	**190**	*31.19*	**265**	*21.90*	**340**	*51.76*
45	*43.67*	**120**	*19.49*	**195**	*30.74*	**270**	*22.70*	**345**	*50.49*
50	*42.05*	**125**	*19.42*	**200**	*29.64*	**275**	*24.30*	**350**	*49.20*
55	*40.26*	**130**	*19.40*	**205**	*28.00*	**280**	*26.08*	**355**	*28.40*
60	*38.17*	**135**	*19.70*	**210**	*26.37*	**285**	*28.59*	**360**	*47.62*
65	*35.72*	**140**	*19.99*	**215**	*24.89*	**290**	*33.59*		
70	*33.37*	**145**	*20.60*	**220**	*23.39*	**295**	*41.12*		
						Featherline		**26°54'**	*48.43*
						Featherline		**316°80'**	*61.66*

Cross-Section Number: 29
Step of measurement, mm: 5
Distance from the Heel Point, mm: 150

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*48.08*	**75**	*29.73*	**150**	*19.92*	**225**	*20.32*	**300**	*48.69*
5	*47.84*	**80**	*27.44*	**155**	*20.51*	**230**	*19.23*	**305**	*54.18*
10	*47.54*	**85**	*25.26*	**160**	*21.52*	**235**	*19.54*	**310**	*59.15*
15	*48.08*	**90**	*21.26*	**165**	*22.57*	**240**	*19.25*	**315**	*62.63*
20	*48.72*	**95**	*21.92*	**170**	*23.57*	**245**	*19.20*	**320**	*60.54*
25	*49.35*	**100**	*20.82*	**175**	*24.34*	**250**	*19.32*	**325**	*58.01*
30	*50.48*	**105**	*19.96*	**180**	*25.34*	**255**	*19.54*	**330**	*55.40*
35	*49.06*	**110**	*19.40*	**185**	*25.75*	**260**	*20.06*	**335**	*53.55*
40	*47.13*	**115**	*18.90*	**190**	*25.94*	**265**	*20.68*	**340**	*51.86*
45	*45.43*	**120**	*18.40*	**195**	*25.58*	**270**	*21.72*	**345**	*50.53*
50	*43.47*	**125**	*18.23*	**200**	*25.07*	**275**	*23.13*	**350**	*49.46*
55	*41.05*	**130**	*18.33*	**205**	*24.17*	**280**	*25.24*	**355**	*48.65*
60	*38.55*	**135**	*18.46*	**210**	*22.85*	**285**	*27.99*	**360**	*48.00*
65	*35.45*	**140**	*18.79*	**215**	*22.03*	**290**	*33.28*		
70	*32.46*	**145**	*19.39*	**220**	*20.82*	**295**	*40.41*		
						Featherline		**30°**	*50.48*
						Featherline		**315°84'**	*63.65*

Cross-Section Number: 30
Step of measurement, mm: 5
Distance from the Heel Point, mm: 155

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*47.80*	**75**	*29.61*	**150**	*17.51*	**225**	*17.98*	**300**	*48.44*
5	*47.60*	**80**	*30.39*	**155**	*17.87*	**230**	*17.37*	**305**	*54.53*
10	*47.55*	**85**	*24.18*	**160**	*18.27*	**235**	*17.33*	**310**	*59.06*
15	*47.81*	**90**	*22.90*	**165**	*19.06*	**240**	*17.25*	**315**	*62.21*
20	*48.36*	**95**	*20.73*	**170**	*19.57*	**245**	*17.34*	**320**	*60.05*
25	*49.59*	**100**	*19.37*	**175**	*20.09*	**250**	*17.53*	**325**	*57.25*
30	*50.55*	**105**	*18.36*	**180**	*20.49*	**255**	*17.85*	**330**	*54.82*
35	*51.23*	**110**	*18.07*	**185**	*20.70*	**260**	*18.30*	**335**	*53.00*
40	*49.29*	**115**	*18.66*	**190**	*20.70*	**265**	*18.98*	**340**	*51.78*
45	*47.04*	**120**	*17.01*	**195**	*20.71*	**270**	*19.89*	**345**	*50.39*
50	*44.60*	**125**	*16.91*	**200**	*20.30*	**275**	*21.45*	**350**	*49.13*
55	*41.91*	**130**	*16.55*	**205**	*19.80*	**280**	*23.01*	**355**	*48.36*
60	*38.78*	**135**	*16.68*	**210**	*19.19*	**285**	*25.95*	**360**	*47.76*
65	*35.46*	**140**	*16.79*	**215**	*18.70*	**290**	*31.79*		
70	*32.17*	**145**	*17.08*	**220**	*18.21*	**295**	*37.29*		
						Featherline		**32°69'**	*51.34*
						Featherline		**315°88'**	*63.23*

Cross-Section Number: 31
Step of measurement, mm: 5
Distance from the Heel Point, mm: 160

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*47.40*	**75**	*28.27*	**150**	*14.32*	**225**	*14.37*	**300**	*47.80*
5	*47.02*	**80**	*25.13*	**155**	*14.40*	**230**	*14.38*	**305**	*51.89*
10	*47.00*	**85**	*22.75*	**160**	*14.44*	**235**	*14.28*	**310**	*57.87*
15	*47.43*	**90**	*20.57*	**165**	*14.67*	**240**	*14.46*	**315**	*61.09*
20	*47.97*	**95**	*19.26*	**170**	*14.88*	**245**	*14.50*	**320**	*59.38*
25	*48.81*	**100**	*18.02*	**175**	*14.88*	**250**	*14.69*	**325**	*56.44*
30	*50.01*	**105**	*16.78*	**180**	*14.95*	**255**	*15.00*	**330**	*54.34*
35	*51.55*	**110**	*15.80*	**185**	*15.16*	**260**	*15.62*	**335**	*52.45*
40	*50.72*	**115**	*15.28*	**190**	*15.00*	**265**	*16.30*	**340**	*50.88*
45	*47.93*	**120**	*14.80*	**195**	*15.35*	**270**	*17.16*	**345**	*49.55*
50	*45.44*	**125**	*14.60*	**200**	*16.38*	**275**	*18.48*	**350**	*48.12*
55	*42.50*	**130**	*14.35*	**205**	*14.90*	**280**	*19.83*	**355**	*47.88*
60	*39.18*	**135**	*14.22*	**210**	*14.88*	**285**	*21.27*	**360**	*47.29*
65	*35.47*	**140**	*14.14*	**215**	*14.59*	**290**	*28.84*		
70	*31.70*	**145**	*14.29*	**220**	*14.40*	**295**	*37.68*		
						Featherline		**36°31'**	*52.10*
						Featherline		**315°91'**	*62.32*

Cross-Section Number: 32
Step of measurement, mm: 5
Distance from the Heel Point, mm: 165

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*46.39*	**75**	*27.26*	**150**	*9.72*	**225**	*9.71*	**300**	*44.77*
5	*46.07*	**80**	*23.43*	**155**	*9.71*	**230**	*9.72*	**305**	*52.18*
10	*46.04*	**85**	*20.31*	**160**	*9.54*	**235**	*9.95*	**310**	*56.61*
15	*46.25*	**90**	*18.10*	**165**	*9.31*	**240**	*10.11*	**315**	*59.88*
20	*46.89*	**95**	*16.29*	**170**	*9.41*	**245**	*10.55*	**320**	*58.76*
25	*47.80*	**100**	*15.00*	**175**	*9.25*	**250**	*11.01*	**325**	*56.05*
30	*48.68*	**105**	*13.70*	**180**	*9.30*	**255**	*11.37*	**330**	*53.52*
35	*50.57*	**110**	*12.94*	**185**	*9.38*	**260**	*12.21*	**335**	*51.43*
40	*52.14*	**115**	*12.49*	**190**	*9.14*	**265**	*12.95*	**340**	*50.03*
45	*49.71*	**120**	*11.88*	**195**	*9.28*	**270**	*12.90*	**345**	*48.66*
50	*46.39*	**125**	*11.14*	**200**	*9.28*	**275**	*15.40*	**350**	*47.50*
55	*42.83*	**130**	*11.01*	**205**	*9.06*	**280**	*16.31*	**355**	*46.46*
60	*39.56*	**135**	*10.42*	**210**	*9.14*	**285**	*20.27*	**360**	*46.29*
65	*35.19*	**140**	*10.40*	**215**	*9.33*	**290**	*24.20*		
70	*31.41*	**145**	*9.99*	**220**	*9.45*	**295**	*37.65*		
						Featherline		**38°95'**	*52.48*
						Featherline		**316°39'**	*61.30*

Cross-Section Number: 33
Step of measurement, mm: 5
Distance from the Heel Point, mm: 170

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*45.17*	**75**	*24.41*	**150**	*4.90*	**225**	*4.50*	**300**	*43.15*
5	*44.90*	**80**	*20.08*	**155**	*4.40*	**230**	*4.56*	**305**	*50.62*
10	*44.95*	**85**	*17.28*	**160**	*4.53*	**235**	*4.79*	**310**	*54.88*
15	*45.46*	**90**	*14.70*	**165**	*4.40*	**240**	*4.85*	**315**	*58.74*
20	*46.00*	**95**	*12.28*	**170**	*4.38*	**245**	*5.75*	**320**	*57.67*
25	*46.93*	**100**	*11.47*	**175**	*4.08*	**250**	*6.11*	**325**	*54.46*
30	*48.08*	**105**	*9.89*	**180**	*4.06*	**255**	*6.52*	**330**	*52.25*
35	*49.42*	**110**	*9.58*	**185**	*4.10*	**260**	*6.55*	**335**	*50.40*
40	*51.70*	**115**	*8.14*	**190**	*4.04*	**265**	*7.82*	**340**	*48.82*
45	*49.61*	**120**	*7.27*	**195**	*3.78*	**270**	*7.80*	**345**	*47.57*
50	*46.35*	**125**	*6.63*	**200**	*4.09*	**275**	*9.91*	**350**	*46.54*
55	*42.87*	**130**	*6.18*	**205**	*4.18*	**280**	*10.75*	**355**	*45.81*
60	*39.49*	**135**	*5.66*	**210**	*4.03*	**285**	*12.67*	**360**	*45.29*
65	*34.49*	**140**	*5.04*	**215**	*4.28*	**290**	*19.18*		
70	*30.05*	**145**	*4.67*	**220**	*4.28*	**295**	*32.06*		
						Featherline		**40°55'**	*52.09*
						Featherline		**316°40'**	*60.05*

Cross-Section Number: 34
Step of measurement, mm: 10
Distance from the Heel Point, mm: 180

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*43.26*	**75**	*14.13*	**150**	*-5.53*	**225**	*-5.90*	**300**	*40.37*
5	*43.33*	**80**	-	**155**	*-5.15*	**230**	*-7.51*	**305**	*37.65*
10	*42.72*	**85**	-	**160**	*-4.65*	**235**	*-6.26*	**310**	*52.39*
15	*43.46*	**90**	-	**165**	*-4.55*	**240**	*-7.62*	**315**	*55.40*
20	*43.98*	**95**	-	**170**	*-4.35*	**245**	*9.36*	**320**	*54.91*
25	*44.85*	**100**	-	**175**	*-4.51*	**250**	-	**325**	*52.18*
30	*45.91*	**105**	-	**180**	*-4.50*	**255**	-	**330**	*49.93*
35	*47.54*	**110**	-	**185**	*-4.39*	**260**	-	**335**	*47.84*
40	*49.49*	**115**	-	**190**	*-4.48*	**265**	-	**340**	*46.41*
45	*48.18*	**120**	-	**195**	*-4.58*	**270**	-	**345**	*45.08*
50	*44.52*	**125**	-	**200**	*-4.65*	**275**	-	**350**	*44.14*
55	*40.00*	**130**	-	**205**	*-4.87*	**280**	-	**355**	*43.58*
60	*36.43*	**135**	*-7.32*	**210**	*-5.22*	**285**	-	**360**	*43.04*
65	*28.35*	**140**	*-6.47*	**215**	*-5.11*	**290**	-		
70	*21.55*	**145**	*-5.97*	**220**	*-5.55*	**295**	-		
						Featherline		**41°85'**	*50.18*
						Featherline		**316°46'**	*52.64*

Cross-Section Number: 35
Step of measurement, mm: 10
Distance from the Heel Point, mm: 190

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	40.68	75	-	150	-11.97	225	-13.69	300	-
5	40.37	80	-	155	-10.87	230	-14.73	305	41.70
10	40.53	85	-	160	-11.62	235	-	310	46.86
15	40.70	90	-	165	-10.61	240	-	315	50.52
20	41.34	95	-	170	-10.77	245	-	320	52.54
25	42.38	100	-	175	-10.37	250	-	325	49.78
30	43.29	105	-	180	-9.91	255	-	330	47.47
35	44.60	110	-	185	-10.31	260	-	335	45.60
40	46.20	115	-	190	-10.30	265	-	340	44.09
45	45.70	120	-	195	-10.81	270	-	345	42.81
50	42.30	125	-	200	-10.78	275	-	350	41.78
55	37.64	130	-	205	-10.92	280	-	355	41.10
60	31.23	135	-	210	-11.31	285	-	360	40.62
65	-	140	-	215	-11.65	290	-		
70	-	145	-	220	-12.48	295	-		
						Featherline		42°28'	47.25
						Featherline		318°97'	53.01

Cross-Section Number: 36
Step of measurement, mm: 10
Distance from the Heel Point, mm: 200

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	37.68	75	-	150	-14.82	225	-	300	-
5	38.44	80	-	155	-14.12	230	-	305	-
10	38.37	85	-	160	-13.44	235	-	310	40.35
15	38.54	90	-	165	-12.95	240	-	315	45.62
20	39.18	95	-	170	-12.47	245	-	320	49.28
25	40.07	100	-	175	-12.21	250	-	325	47.38
30	41.60	105	-	180	-12.17	255	-	330	45.32
35	42.34	110	-	185	-12.20	260	-	335	43.51
40	43.89	115	-	190	-12.32	265	-	340	41.71
45	42.05	120	-	195	-12.35	270	-	345	40.56
50	31.30	125	-	200	-12.31	275	-	350	39.67
55	32.36	130	-	205	-13.52	280	-	355	39.09
60	28.28	135	-	210	-13.59	285	-	360	37.84
65	-	140	-	215	-14.21	290	-		
70	-	145	-15.04	220	-15.15	295	-		
						Featherline		41°56'	44.34
						Featherline		320°15'	49.33

Cross-Section Number: 37
Step of measurement, mm: 10
Distance from the Heel Point, mm: 210

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*36.29*	**75**	-	**150**	*-15.37*	**225**	*-18.50*	**300**	-
5	*36.35*	**80**	-	**155**	*-14.78*	**230**	-	**305**	-
10	*36.11*	**85**	-	**160**	*-14.01*	**235**	-	**310**	*35.23*
15	*36.28*	**90**	-	**165**	*-13.68*	**240**	-	**315**	*39.67*
20	*36.83*	**95**	-	**170**	*-12.99*	**245**	-	**320**	*43.77*
25	*37.46*	**100**	-	**175**	*-12.74*	**250**	-	**325**	*44.64*
30	*38.40*	**105**	-	**180**	*-13.04*	**255**	-	**330**	*41.70*
35	*39.72*	**110**	-	**185**	*-12.89*	**260**	--	**335**	*40.72*
40	*39.57*	**115**	-	**190**	*-13.18*	**265**	-	**340**	*39.23*
45	*35.81*	**120**	-	**195**	*-13.18*	**270**	-	**345**	*38.08*
50	*31.30*	**125**	-	**200**	*-13.72*	**275**	-	**350**	*37.05*
55	*24.64*	**130**	-	**205**	*-14.18*	**280**	-	**355**	*36.06*
60	-	**135**	-	**210**	*-14.90*	**285**	-	**360**	*35.72*
65	-	**140**	-	**215**	*-15.49*	**290**	-		
70	-	**145**	*-15.67*	**220**	*-16.90*	**295**	-		
						Featherline		**40°40'**	*40.56*
						Featherline		**322°22'**	*45.58*

Cross-Section Number: 38
Step of measurement, mm: 10
Distance from the Heel Point, mm: 220

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	-	**75**	-	**150**	*-15.27*	**225**	-	**300**	-
5	-	**80**	-	**155**	*-14.19*	**230**	-	**305**	-
10	-	**85**	-	**160**	*-13.85*	**235**	-	**310**	-
15	*33.43*	**90**	-	**165**	*-13.58*	**240**	-	**315**	*32.73*
20	*34.11*	**95**	-	**170**	*-13.80*	**245**	-	**320**	*37.01*
25	*34.58*	**100**	-	**175**	*-12.58*	**250**	-	**325**	*40.59*
30	*35.51*	**105**	-	**180**	*-12.58*	**255**	-	**330**	*39.81*
35	*36.48*	**110**	-	**185**	*-12.29*	**260**	-	**335**	*38.10*
40	*33.06*	**115**	-	**190**	*-12.93*	**265**	-	**340**	*36.80*
45	*27.31*	**120**	-	**195**	*-12.94*	**270**	-	**345**	-
50	-	**125**	-	**200**	*-13.98*	**275**	-	**350**	-
55	-	**130**	-	**205**	*-14.20*	**280**	-	**355**	-
60	-	**135**	-	**210**	*-15.60*	**285**	-	**360**	-
65	-	**140**	-	**215**	*-16.21*	**290**	-		
70	-	**145**	*-16.59*	**220**	*-17.77*	**295**	-		
						Featherline		**35°43'**	*36.59*
						Featherline		**325°65'**	*41.38*

Cross-Section Number: 39
Step of measurement, mm: 10
Distance from the Heel Point, mm: 230

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	-	75	-	150	-15.61	225	-	300	-
5	-	80	-	155	-14.02	230	-	305	-
10	-	85	-	160	-13.16	235	-	310	-
15	30.70	90	-	165	-12.40	240	-	315	-
20	31.04	95	-	170	-12.37	245	-	320	26.80
25	31.69	100	-	175	-11.92	250	-	325	32/35
30	32.50	105	-	180	-11.97	255	-	330	35.85
35	28.68	110	-	185	-12.12	260	-	335	35.39
40	25.01	115	-	190	-12.14	265	-	340	34.23
45	-	120	-	195	-10.60	270	-	345	-
50	-	125	-	200	-13.52	275	-	350	-
55	-	130	-	205	-14.16	280	-	355	-
60	-	135	-	210	-15.81	285	-	360	-
65	-	140	-	215	-17.62	290	-		
70	-	145	-	220	-18.45	295	-		
						Featherline		31°03'	32.55
						Featherline		330°32'	35.88

Cross-Section Number: 40
Step of measurement, mm: 10
Distance from the Heel Point, mm: 240

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	-	75	-	150	-17.57	225	-	300	-
5	-	80	-	155	-15.70	230	-	305	-
10	-	85	-	160	-14.12	235	-	310	-
15	27.80	90	-	165	-13.77	240	-	315	-
20	28.12	95	-	170	-13.34	245	-	320	-
25	28.30	100	-	175	-13.15	250	-	325	-
30	21.49	105	-	180	-13.51	255	-	330	27.65
35	-	110	-	185	-13.46	260	-	335	31.47
40	-	115	-	190	-13.65	265	-	340	-
45	-	120	-	195	-14.35	270	-	345	-
50	-	125	-	200	-15.56	275	-	350	-
55	-	130	-	205	-16.90	280	-	355	-
60	-	135	-	210	-18.22	285	-	360	-
65	-	140	-	215	-	290	-		
70	-	145	-	220	-	295	-		
						Featherline		25°23'	28.30
						Featherline		335°	31.47

Appendix F

2Dlst.ini Data File For The Last No 873

;Location of adjustment points		
right side		3
left side		3
;VGA-14" 22,22; EGA 22,15		
;screen scale tuning		
horizontal size		26
vertical size		25.2
displacement to the left		55
displacement down		450
;Global modifications		
toes turning		0
heel height		0
displacement in toe section		4
displacement in ball joint section		5
;Table 1 "Bottom"		
heel point	x	0
	y	248
;Node points		
left heel	x	17
	y	185
right heel	x	-32
	y	185
left shank	x	10
	y	145
right shank	x	-37
	y	145
left ball joint	x	31
	y	90
right ball joint	x	-45
	y	90
left forepart	x	23
	y	30
right forepart	x	-26
	y	30
toe point	x	0
	y	3.5
; "0" derivatives		
left heel	x	11
	y	248
right heel	x	-15
	y	248
left shank	x	12
	y	173

right shank	x	-33
	y	177
left ball joint	x	7
	y	128
right ball joint	x	-39
	y	138
left toes	x	35
	y	82
right toes	x	-43
	y	74
left forepart	x	18
	y	14
right forepart	x	-17
	y	12
;"1" derivatives		
left heel	x	27
	y	215
right heel	x	-27
	y	234
left shank	x	9
	y	160
right shank	x	-36
	y	151
left ball joint	x	23
	y	105
right ball joint	x	-46
	y	102
left toes	x	34
	y	57
right toes	x	-35
	y	48
left forepart	x	6
	y	3.5
right forepart	x	-6
	y	3.5
;Table2 "Profile"		
;Last No 873, size 38.5		
heel point	y	248
	z	0
waist	y	250.5
	z	53
cone top plane	y	244
	z	80
heel	y	185
	z	80
shank	y	145
	z	103
ball joint	y	90
	z	53
forepart	y	30

	z	28
toe point	y	3.5
	z	0
;"0" derivatives		
waist	y	253
	z	22
cone top plane	y	249
	z	61
heel	y	244
	z	80
shank	y	185
	z	80
ball joint	y	140
	z	98
toes	y	80
	z	43
forepart	y	12
	z	25.5
;"1" derivatives		
waist	y	253
	z	38
cone top plane	y	250
	z	63
heel	y	185
	z	80
shank	y	145
	z	103
ball joint	y	95
	z	57
toes	y	55
	z	31
forepart	y	3.5
	z	15
;Table 3 "Cone top plane"		
;Last No 873, size 38.5		
height of the heel	z	80
height of the shank	z	103
cone top plane point	x	0
	y	243
left heel	x	14
	y	185
right heel	x	-9
	y	185
shank	x	0
	y	144
;"0" derivatives		
left heel	x	9
	y	243
right heel	x	-4
	y	243

left shank	x	11
	y	160
right shank	x	-8
	y	167
;"1" derivatives		
left heel	x	16.5
	y	208
right heel	x	-11
	y	215
left shank	x	5
	y	144
right shank	x	-3
	y	144
;Table 4 "Waist"		
;Last No 873, size 38.5		
height of the waist	z	53
waist point	x	0
	y	254
left heel	x	21
	y	186
right heel	x	-18
	y	186
left shank	x	22
	y	145.5
right shank	x	-18
	y	145.5
ball joint	x	0
	y	90
;"0" derivatives		
left heel	x	10
	y	254
right heel	x	-10
	y	254
left shank	x	21
	y	186
right shank	x	-18
	y	186
left ball joint	x	23
	y	108.5
right ball joint	x	-18
	y	120.5
;"1" derivatives		
left heel	x	21
	y	202
right heel	x	-18
	y	206
left shank	x	22
	y	145.5
right shank	x	-18
	y	145.5

left ball joint	x	13
	y	90
right ball joint	x	-5
	y	90
;Table 5 "Girths"		
;Last No 873, size 38.5		
;Table 5.1 "Heel"		
"y" of the heel	y	185
;"0" derivatives		
left bottom	x	29
	z	39
right bottom	x	-36
	z	22.5
left frontcone profile	x	14
	z	74
right frontcone profile	x	-16
	z	56
;"1" derivatives		
left bottom	x	23
	z	18
right bottom	x	-25
	z	38
left frontcone profile	x	20
	z	57
right frontcone profile	x	-10
	z	73
;Table 5.2 "Shank"		
"y" of the shank	y	145
;"0" derivatives		
left bottom	x	30
	z	39
right bottom	x	-41
	z	24
left frontcone profile	x	5
	z	102
right frontcone profile	x	-2
	z	63
;"1" derivatives		
left bottom	x	21
	z	18
right bottom	x	-21
	z	45
left frontcone profile	x	19
	z	59
right frontcone profile	x	-14
	z	102
;Table 5.3 "Ball joint"		
"y" of the ball joint	y	90
;"0" derivatives		
left bottom	x	13

	z	53
right bottom	x	-45
	z	23
;"1" derivatives		
left bottom	x	44
	z	21
right bottom	x	-19.5
	z	53
;Table 5.4 "Toes"		
"y" of the toes	y	30
;"0" derivatives		
left bottom	x	13
	z	26
right bottom	x	-25
	z	15.5
;"1" derivatives		
left bottom	x	24
	z	16
right bottom	x	-14
	z	26

Appendix H

3DIst.ini Data File For The Last No 873

;Location of adjustment points		
right side		3
left side		3
;VGA-14" 22,22; EGA 22,15		
;screen scale tuning		
horizontal size		26
vertical size		25.2
displacement to the left		55
displacement down		450
;Global modifications		
toes turning		0
heel height		0
displacement in toe section		4
displacement in ball joint section		5
heel point		0
;Table 1 "Bottom"		
heel point	x	0
	y	252
;Node points		
left heel	x	17
	y	198
	z	25
right heel	x	-32.5
	y	198
	z	25
left shank	x	7
	y	152
	z	20
right shank	x	-37
	y	152
	z	21
left ball joint	x	30.5
	y	92
	z	4.5
right ball joint	x	-44
	y	92
	z	4.5
left forepart	x	25
	y	40.5
	z	16
right forepart	x	-28.5
	y	40.5
	z	16

toe point	x	0
	y	0
	z	25.5
; "0" derivatives		
left heel	x	11
	y	252
	z	23
right heel	x	-17
	y	252
	z	23
left shank	x	13
	y	184
	z	25.5
right shank	x	-34
	y	184
	z	26
left ball joint	x	5
	y	122
	z	13.5
right ball joint	x	-40
	y	128
	z	15
left toes	x	37.5
	y	77
	z	6.5
right toes	x	-42
	y	72
	z	7
left forepart	x	17
	y	18
	z	22
right forepart	x	-21.5
	y	27
	z	19
;"1" derivatives		
left heel	x	30
	y	242
	z	24
right heel	x	-29
	y	242
	z	24
left shank	x	8.5
	y	172
	z	27
right shank	x	-34
	y	168
	z	26.5
left ball joint	x	21.5
	y	112
	z	2

right ball joint	x	-46
	y	102
	z	2.5
left toes	x	31
	y	62
	z	10.5
right toes	x	-35.5
	y	59
	z	12
left forepart	x	9.5
	y	0
	z	25.5
right forepart	x	-10.5
	y	0
	z	25.5
;Table2 "Profile"		
;Last No 873, size 38.5		
heel point	y	252
	z	24
waist	y	258
	z	61
cone top plane	y	254
	z	90
heel	y	198
	z	90
shank	y	152
	z	116
ball joint	y	92
	z	61
forepart	y	40
	z	38
toe point	y	0
	z	25.5
;"0" derivatives		
waist	y	256
	z	32
cone top plane	y	258
	z	70
heel	y	237
	z	90
shank	y	182
	z	90
ball joint	y	127
	z	99.5
toes	y	72
	z	39
forepart	y	12
	z	40
;"1" derivatives		
waist	y	259.5

	z	51
cone top plane	y	257
	z	78
heel	y	217
	z	90
shank	y	168
	z	107
ball joint	y	107
	z	80
toes	y	54
	z	37
forepart	y	5
	z	39
;Table 3 "Cone top plane"		
;Last No 873, size 38.5		
height of the heel	z	90
height of the shank	z	116
cone top plane point	x	0
	y	254
left heel	x	12
	y	198
right heel	x	-13
	y	198
shank	x	0
	y	152
;"0" derivatives		
left heel	x	7
	y	254
right heel	x	-7
	y	254
left shank	x	12
	y	182
right shank	x	-15
	y	178
;"1" derivatives		
left heel	x	11.5
	y	212
right heel	x	-12
	y	212
left shank	x	5
	y	152
right shank	x	-9
	y	152
;Table 4 "Waist"		
;Last No 873, size 38.5		
height of the waist	z	61
waist point	x	0
	y	258
left heel	x	19
	y	197

right heel	x	-20.5
	y	152
left shank	x	17.5
	y	152
right shank	x	-21
	y	152
ball joint	x	0
	y	92
;"0" derivatives		
left heel	x	10
	y	258
right heel	x	-10
	y	258
left shank	x	19.5
	y	186
right shank	x	-21.5
	y	187
left ball joint	x	15.5
	y	121
right ball joint	x	-20.5
	y	122
;"1" derivatives		
left heel	x	18
	y	226
right heel	x	-19
	y	226
left shank	x	19.5
	y	170
right shank	x	-22
	y	167
left ball joint	x	10
	y	92
right ball joint	x	-10
	y	92
;Table 5 "Girths"		
;Last No 873, size 38.5		
;Table 5.1 "Heel"		
"y" of the heel	y	198
;"0" derivatives		
left bottom	x	28.5
	z	43
right bottom	x	-39.5
	z	38
left frontcone profile	x	14.5
	z	78
right frontcone profile	x	-14.5
	z	70.5
;"1" derivatives		
left bottom	x	28
	z	38.5

right bottom	x	-34
	z	41.5
left frontcone profile	x	14
	z	74.5
right frontcone profile	x	-12.5
	z	80
;Table 5.2 “Shank”		
“y” of the shank	y	152
;”0” derivatives		
left bottom	x	34
	z	38
right bottom	x	-47.5
	z	33.5
left frontcone profile	x	5
	z	116
right frontcone profile	x	-12
	z	88.5
;”1” derivatives		
left bottom	x	24.5
	z	31
right bottom	x	-25
	z	47
left frontcone profile	x	7
	z	76
right frontcone profile	x	-10
	z	116
;Table 5.3 “Ball joint”		
“y” of the ball joint	y	92
;”0” derivatives		
left bottom	x	10
	z	61
right bottom	x	-47.5
	z	30.5
;”1” derivatives		
left bottom	x	44
	z	33
right bottom	x	-10
	z	61
;Table 5.4 “Toes”		
“y” of the toes	y	40
;”0” derivatives		
left bottom	x	15
	z	38
right bottom	x	-23.5
	z	37
;”1” derivatives		
left bottom	x	5
	z	37
right bottom	x	-15
	z	38

Appendix I

Shoe Last No 875 Measurement Data

(Size: 38,5; Stick length: 254 mm)

Cross-Section Number: 1
Step of measurement, mm: 0
Distance from the Heel Point, mm: 0

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	25.52	75	10.96	150	-	225	12.15	300	16.27
5	26.34	80	10.34	155	-	230	11.76	305	17.77
10	26.33	85	9.85	160	22.75	235	11.30	310	19.52
15	25.49	90	9.60	165	24.37	240	11.08	315	20.73
20	24.38	95	9.71	170	29.84	245	10.90	320	22.11
25	23.58	100	9.61	175	32.39	250	10.77	325	23.79
30	22.28	105	9.52	180	35.96	255	10.66	330	24.93
35	21.22	110	9.56	185	32.26	260	10.80	335	26.02
40	19.42	115	11.86	190	29.93	265	11.08	340	26.25
45	18.24	120	12.15	195	22.26	270	11.39	345	27.66
50	17.19	125	12.44	200	21.25	275	11.40	350	28.00
55	16.30	130	12.94	205	-	280	11.99	355	27.97
60	14.88	135	13.65	210	-	285	12.74	360	25.52
65	14.31	140	14.04	215	-	290	13.60		
70	13.53	145	-	220	13.07	295	15.45		
						Featherline		5°	26.34
						Cone Top Plane		175°	32.39
						Cone Top Plane		180°	35.96
						Featherline		340°	26.25

Cross-Section Number: 2
Step of measurement, mm: 5
Distance from the Heel Point, mm: 5

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	28.76	75	17.15	150	-	225	14.10	300	21.08
5	28.98	80	16.15	155	-	230	13.52	305	23.26
10	29.06	85	15.15	160	26.26	235	13.05	310	24.97
15	29.45	90	14.70	165	30.47	240	12.62	315	26.21
20	29.85	95	14.37	170	35.92	245	12.58	320	18.50
25	30.32	100	14.40	175	38.89	250	12.94	325	30.19
30	28.92	105	14.40	180	38.28	255	12.93	330	31.17
35	27.71	110	14.44	185	38.46	260	13.06	335	31.58
40	26.28	115	14.72	190	33.27	265	13.32	340	30.46
45	24.82	120	14.44	195	27.50	270	14.17	345	29.59
50	23.32	125	15.08	200	23.16	275	14.81	350	29.05
55	21.83	130	15.56	205	-	280	15.35	355	28.75
60	20.41	135	16.40	210	-	285	16.70	360	28.76
65	19.30	140	-	215	-	290	18.06		
70	17.97	145	-	220	14.98	295	19.50		
						Featherline		30°	28.92

						Cone Top Plane	**170°**	*35.92*
						Profile	**180°**	*38.28*
						Cone Top Plane	**190°**	*33.27*
						Featherline	**330°**	*31.17*

Cross-Section Number: 3

Step of measurement, mm: 5

Distance from the Heel Point, mm: 10

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*29.19*	**75**	*20.30*	**150**	-	**225**	*15.42*	**300**	*26.13*
5	*29.28*	**80**	*19.10*	**155**	-	**230**	*14.93*	**305**	*27.89*
10	*29.46*	**85**	*18.07*	**160**	*28.69*	**235**	*14.58*	**310**	*29.92*
15	*29.92*	**90**	*17.33*	**165**	*34.63*	**240**	*14.35*	**315**	*31.98*
20	*30.55*	**95**	*16.82*	**170**	*39.42*	**245**	*14.32*	**320**	*35.29*
25	*31.36*	**100**	*16.42*	**175**	*37.90*	**250**	*14.37*	**325**	*34.56*
30	*32.36*	**105**	*16.20*	**180**	*37.73*	**255**	*14.56*	**330**	*33.35*
35	*33.16*	**110**	*16.13*	**185**	*37.99*	**260**	*15.03*	**335**	*31.98*
40	*30.76*	**115**	*16.10*	**190**	*36.94*	**265**	*15.70*	**340**	*30.88*
45	*29.19*	**120**	*16.53*	**195**	*30.10*	**270**	*16.46*	**345**	*30.19*
50	*27.67*	**125**	*16.83*	**200**	*25.62*	**275**	*17.55*	**350**	*29.63*
55	*26.16*	**130**	*17.24*	**205**	-	**280**	*18.70*	**355**	*29.33*
60	*24.20*	**135**	*18.10*	**210**	-	**285**	*20.48*	**360**	*29.19*
65	*23.02*	**140**	-	**215**	-	**290**	*22.07*		
70	*21.48*	**145**	-	**220**	*16.99*	**295**	*24.53*		
						Featherline		**35°**	*33.16*
						Cone Top Plane		**170°**	*39.42*
						Cone Top Plane		**188°50'**	*37.94*
						Featherline		**326°**	*35.29*

Cross-Section Number: 4

Step of measurement, mm: 5

Distance from the Heel Point, mm: 15

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*30.08*	**75**	*21.35*	**150**	-	**225**	*18.06*	**300**	*29.07*
5	*30.41*	**80**	*19.35*	**155**	*27.56*	**230**	*17.64*	**305**	*30.34*
10	*31.04*	**85**	*18.45*	**160**	*34.37*	**235**	*17.52*	**310**	*32.22*
15	*31.65*	**90**	*17.35*	**165**	*38.20*	**240**	*17.30*	**315**	*33.48*
20	*32.53*	**95**	*16.56*	**170**	*37.99*	**245**	*17.41*	**320**	*33.99*
25	*33.77*	**100**	*15.87*	**175**	*37.90*	**250**	*17.45*	**325**	*32.92*
30	*35.62*	**105**	*15.67*	**180**	*38.02*	**255**	*17.95*	**330**	*31.77*
35	*37.09*	**110**	*15,57*	**185**	*38.52*	**260**	*18.60*	**335**	*31.05*
40	*35.59*	**115**	*15.57*	**190**	*34.66*	**265**	*19.40*	**340**	*30.37*
45	*33.15*	**120**	*15,85*	**195**	*29.37*	**270**	*29.18*	**345**	*30.08*
50	*31.21*	**125**	*16.20*	**200**	-	**275**	*21.42*	**350**	*29.94*
55	*29.82*	**130**	*16.90*	**205**	-	**280**	*22.84*	**355**	*29.87*
60	*27.10*	**135**	*17.65*	**210**	-	**285**	*24.89*	**360**	*30.02*
65	*25.07*	**140**	-	**215**	-	**290**	*26.13*		
70	*22.92*	**145**	-	**220**	*18.73*	**295**	*27.65*		
						Featherline		**37°13'**	*37.05*
						Cone Top Plane		**166°**	*34.37*

						Cone Top Plane	190°	34.66
						Featherline	315°	33.48

Cross-Section Number: 5
Step of measurement, mm: 5
Distance from the Heel Point, mm: 20

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	29.06	**75**	21.86	**150**	-	**225**	18.55	**300**	30.79
5	29.56	**80**	20.53	**155**	-	**230**	18.20	**305**	32.13
10	30.22	**85**	19.26	**160**	-	**235**	17.87	**310**	32.45
15	32.22	**90**	18.01	**165**	38.17	**240**	17.85	**315**	34.85
20	33.31	**95**	17.22	**170**	37.74	**245**	17.94	**320**	34.17
25	34.28	**100**	16.56	**175**	37.52	**250**	18.26	**325**	33.05
30	35.91	**105**	16.20	**180**	37.80	**255**	18.56	**330**	32.03
35	37.53	**110**	16.16	**185**	38.43	**260**	19.17	**335**	31.44
40	37.45	**115**	16.23	**190**	35.80	**265**	20.16	**340**	30.87
45	35.62	**120**	16.15	**195**	-	**270**	21.31	**345**	29.09
50	33.82	**125**	16.62	**200**	-	**275**	22.63	**350**	28.98
55	32.95	**130**	17.14	**205**	-	**280**	24.31	**355**	28.97
60	29.92	**135**	-	**210**	-	**285**	25.95	**360**	29.11
65	27.10	**140**	-	**215**	-	**290**	27.91		
70	23.83	**145**	-	**220**	-	**295**	29.02		
						Featherline		**40°**	37.45
						Cone Top Plane		**159°59'**	34.08
						Cone Top Plane		**190°**	35.80
						Featherline		**314°99'**	34.84

Cross-Section Number: 6
Step of measurement, mm: 5
Distance from the Heel Point, mm: 25

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	28.65	**75**	22.67	**150**	-	**225**	19.08	**300**	31.97
5	29.68	**80**	20.84	**155**	30.00	**230**	18.50	**305**	33.77
10	30.28	**85**	19.34	**160**	36.68	**235**	18.33	**310**	34.42
15	31.08	**90**	18.42	**165**	37.60	**240**	18.00	**315**	35.85
20	33.50	**95**	17.74	**170**	37.20	**245**	18.36	**320**	34.30
25	34.48	**100**	17.03	**175**	37.12	**250**	18.73	**325**	33.08
30	35.51	**105**	16.80	**180**	37.45	**255**	19.25	**330**	32.15
35	37.60	**110**	16.63	**185**	38.45	**260**	19.94	**335**	31.38
40	38.41	**115**	16.56	**190**	36.72	**265**	20.84	**340**	29.82
45	37.18	**120**	16.84	**195**	31.05	**270**	22.22	**345**	29.36
50	35.23	**125**	17.11	**200**	-	**275**	23.30	**350**	29.24
55	33.12	**130**	17.92	**205**	-	**280**	25.22	**355**	29.17
60	30.96	**135**	-	**210**	-	**285**	27.02	**360**	28.62
65	28.11	**140**	-	**215**	-	**290**	28.91		
70	25.38	**145**	-	**220**	-	**295**	30.64		
						Featherline		**40°**	38.41
						Cone Top Plane		**157°85'**	34.70
						Cone Top Plane		**191°92'**	35.01
						Featherline		**313°67'**	35.61

Cross-Section Number: 7
Step of measurement, mm: 5
Distance from the Heel Point, mm: 30

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*29.58*	**75**	*25.70*	**150**	*24.77*	**225**	*17.96*	**300**	*34.63*
5	*29.59*	**80**	*24.21*	**155**	*27.78*	**230**	*17.25*	**305**	*36.34*
10	*30.29*	**85**	*22.43*	**160**	*32.03*	**235**	*16.95*	**310**	*38.20*
15	*30.00*	**90**	*21.02*	**165**	*38.18*	**240**	*16.91*	**315**	*39.92*
20	*31.86*	**95**	*20.16*	**170**	*37.58*	**245**	*16.89*	**320**	*37.90*
25	*32.45*	**100**	*19.39*	**175**	*37.52*	**250**	*17.00*	**325**	*36.02*
30	*33.34*	**105**	*18.97*	**180**	*36.79*	**255**	*17.42*	**330**	*34.60*
35	*34.80*	**110**	*18.43*	**185**	*37.93*	**260**	*18.13*	**335**	*33.53*
40	*36.06*	**115**	*18.38*	**190**	*38.09*	**265**	*18.92*	**340**	*31.01*
45	*34.71*	**120**	*18.32*	**195**	*36.28*	**270**	*20.19*	**345**	*30.43*
50	*33.48*	**125**	*18.70*	**200**	*29.86*	**275**	*21.19*	**350**	*29.71*
55	*32.01*	**130**	*19.21*	**205**	*25.26*	**280**	*24.02*	**355**	*29.44*
60	*30.65*	**135**	*20.04*	**210**	*22.70*	**285**	*26.87*	**360**	*29.05*
65	*28.92*	**140**	*21.12*	**215**	*20.14*	**290**	*29.74*		
70	*27.22*	**145**	*22.69*	**220**	*19.04*	**295**	*32.06*		
						Featherline		**39°22'**	*35.99*
						Cone Top Plane		**165°**	*38.18*
						Cone Top Plane		**193°36'**	*38.17*
						Featherline		**315°**	*39.92*

Cross-Section Number: 8
Step of measurement, mm: 5
Distance from the Heel Point, mm: 35

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*29.70*	**75**	*26.25*	**150**	*25.31*	**225**	*18.24*	**300**	*35.57*
5	*29.70*	**80**	*24.32*	**155**	*28.52*	**230**	*17.57*	**305**	*37.25*
10	*29.93*	**85**	*23.05*	**160**	*32.72*	**235**	*17.35*	**310**	*39.09*
15	*31.23*	**90**	*21.71*	**165**	*37.46*	**240**	*17.19*	**315**	*40.45*
20	*31.97*	**95**	*20.53*	**170**	*37.99*	**245**	*17.11*	**320**	*38.29*
25	*32.67*	**100**	*19.83*	**175**	*37.18*	**250**	*17.21*	**325**	*36.28*
30	*33.67*	**105**	*19.19*	**180**	*37.46*	**255**	*17.72*	**330**	*34.86*
35	*34.90*	**110**	*18.97*	**185**	*37.75*	**260**	*18.40*	**335**	*33.55*
40	*36.09*	**115**	*18.95*	**190**	*38.13*	**265**	*19.26*	**340**	*31.40*
45	*34.90*	**120**	*18.97*	**195**	*37.55*	**270**	*20.79*	**345**	*30.60*
50	*33.58*	**125**	*19.24*	**200**	*30.65*	**275**	*22.61*	**350**	*30.28*
55	*32.36*	**130**	*19.62*	**205**	*26.06*	**280**	*24.58*	**355**	*30.02*
60	*31.09*	**135**	*20.51*	**210**	*22.37*	**285**	*27.69*	**360**	*29.21*
65	*29.46*	**140**	*21.67*	**215**	*20.61*	**290**	*30.32*		
70	*27.85*	**145**	*23.27*	**220**	*19.13*	**295**	*32.48*		
						Featherline		**40°**	*36.09*
						Cone Top Plane		**165°**	*37.46*
						Cone Top Plane		**195°**	*37.55*
						Featherline		**314°41'**	*40.62*

Cross-Section Number: 9
Step of measurement, mm: 5
Distance from the Heel Point, mm: 40

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*29.87*	**75**	*24.79*	**150**	*27.19*	**225**	*19.91*	**300**	*32.60*
5	*30.42*	**80**	*22.41*	**155**	*31.61*	**230**	*19.42*	**305**	*33.72*
10	*30.76*	**85**	*20.47*	**160**	*37.36*	**235**	*19.25*	**310**	*34.95*
15	*31.66*	**90**	*19.34*	**165**	*37.50*	**240**	*19.29*	**315**	*35.10*
20	*34.24*	**95**	*18.30*	**170**	*37.10*	**245**	*19.39*	**320**	*34.64*
25	*35.42*	**100**	*17.67*	**175**	*36.11*	**250**	*19.88*	**325**	*33.40*
30	*36.74*	**105**	*17.40*	**180**	*37.40*	**255**	*20.55*	**330**	*32.65*
35	*38.29*	**110**	*17.28*	**185**	*37.06*	**260**	*21.20*	**335**	*31.97*
40	*40.76*	**115**	*17.21*	**190**	*37.49*	**265**	*22.18*	**340**	*31.48*
45	*39.78*	**120**	*17.26*	**195**	*32.39*	**270**	*23.66*	**345**	*30.06*
50	*38.08*	**125**	*17.85*	**200**	*28.02*	**275**	*25.65*	**350**	*29.98*
55	*36.10*	**130**	*18.79*	**205**	*25.03*	**280**	*27.23*	**355**	*29.96*
60	*32.58*	**135**	*19.60*	**210**	*22.96*	**285**	*28.78*	**360**	*29.59*
65	*39.48*	**140**	*20.91*	**215**	*21.56*	**290**	*30.21*		
70	*27.63*	**145**	*22.91*	**220**	*20.31*	**295**	*30.98*		
						Featherline		**41°59'**	*40.48*
						Cone Top Plane		**156°36'**	*33.72*
						Cone Top Plane		**193°08'**	*34.96*
						Featherline		**315°**	*35.10*

Cross-Section Number: 10
Step of measurement, mm: 5
Distance from the Heel Point, mm: 45

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*30.40*	**75**	*24.98*	**150**	*27.44*	**225**	*20.05*	**300**	*32.52*
5	*30.82*	**80**	*22.01*	**155**	*31.74*	**230**	*19.71*	**305**	*33.58*
10	*31.25*	**85**	*20.65*	**160**	*38.42*	**235**	*19.32*	**310**	*34.20*
15	*33.39*	**90**	*19.26*	**165**	*37.03*	**240**	*19.32*	**315**	*34.85*
20	*34.45*	**95**	*18.69*	**170**	*36.36*	**245**	*19.69*	**320**	*34.66*
25	*35.36*	**100**	*17.99*	**175**	*36.21*	**250**	*20.28*	**325**	*33.51*
30	*36.95*	**105**	*17.64*	**180**	*36.58*	**255**	*20.81*	**330**	*32.66*
35	*38.96*	**110**	*17.38*	**185**	*36.66*	**260**	*21.39*	**335**	*32.10*
40	*41.25*	**115**	*17.43*	**190**	*36.67*	**265**	*22.86*	**340**	*31.56*
45	*40.52*	**120**	*17.87*	**195**	*32.06*	**270**	*24.11*	**345**	*31.37*
50	*38.45*	**125**	*18.21*	**200**	*27.83*	**275**	*25.73*	**350**	*30.09*
55	*36.46*	**130**	*18.86*	**205**	*25.12*	**280**	*27.11*	**355**	*30.02*
60	*34.08*	**135**	*19.98*	**210**	*23.15*	**285**	*28.68*	**360**	*30.30*
65	*31.20*	**140**	*21.56*	**215**	*21.75*	**290**	*30.12*		
70	*27.26*	**145**	*24.00*	**220**	*20.65*	**295**	*31.32*		
						Featherline		**41°51'**	*41.00*
						Cone Top Plane		**156°44'**	*34.05*
						Cone Top Plane		**192°83'**	*34.36*
						Featherline		**315°**	*34.85*

Cross-Section Number: 11
Step of measurement, mm: 10
Distance from the Heel Point, mm: 55

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*32.14*	**75**	*28.19*	**150**	*23.46*	**225**	*19.90*	**300**	*34.34*
5	*31.74*	**80**	*26.67*	**155**	*25.86*	**230**	*19.13*	**305**	*37.35*
10	*31.71*	**85**	*25.13*	**160**	*28.61*	**235**	*18.46*	**310**	*39.72*
15	*31.80*	**90**	*23.83*	**165**	*32.36*	**240**	*17.73*	**315**	*41.77*
20	*31.86*	**95**	*22.51*	**170**	*36.82*	**245**	*17.25*	**320**	*42.84*
25	*32.15*	**100**	*21.59*	**175**	*36.52*	**250**	*17.19*	**325**	*40.63*
30	*32.86*	**105**	*20.87*	**180**	*36.18*	**255**	*17.27*	**330**	*38.27*
35	*33.76*	**110**	*20.25*	**185**	*36.33*	**260**	*17.69*	**335**	*36.89*
40	*34.35*	**115**	*19.85*	**190**	*36.47*	**265**	*18.37*	**340**	*35.55*
45	*33.77*	**120**	*19.60*	**195**	*36.93*	**270**	*19.93*	**345**	*34.34*
50	*33.14*	**125**	*19.57*	**200**	*37.68*	**275**	*20.33*	**350**	*33.52*
55	*32.51*	**130**	*19.84*	**205**	*32.13*	**280**	*21.99*	**355**	*32.69*
60	*31.64*	**135**	*20.15*	**210**	*26.90*	**285**	*24.24*	**360**	*32.11*
65	*30.72*	**140**	*20.92*	**215**	*23.55*	**290**	*27.07*		
70	*29.57*	**145**	*21.93*	**220**	*21.63*	**295**	*30.06*		
						Featherline		**40°**	*34.35*
						Cone Top Plane		**170°**	*36.82*
						Profile		**185°**	*36.33*
						Cone Top Plane		**200°**	*37.68*
						Featherline		**320°**	*42.84*

Cross-Section Number: 12
Step of measurement, mm: 10
Distance from the Heel Point, mm: 65

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*33.35*	**75**	*28.66*	**150**	*23.73*	**225**	*20.35*	**300**	*34.15*
5	*33.01*	**80**	*26.86*	**155**	*26.05*	**230**	*19.14*	**305**	*37.52*
10	*32.88*	**85**	*25.14*	**160**	*28.95*	**235**	*19.54*	**310**	*40.44*
15	*32.83*	**90**	*23.53*	**165**	*33.22*	**240**	*17.88*	**315**	*42.66*
20	*33.01*	**95**	*22.35*	**170**	*37.90*	**245**	*17.51*	**320**	*43.96*
25	*33.41*	**100**	*21.44*	**175**	*39.89*	**250**	*18.91*	**325**	*42.78*
30	*33.84*	**105**	*22.32*	**180**	*39.37*	**255**	*17.38*	**330**	*40.34*
35	*34.32*	**110**	*20.16*	**185**	*39.16*	**260**	*17.60*	**335**	*38.47*
40	*33.88*	**115**	*20.01*	**190**	*39.06*	**265**	*18.03*	**340**	*36.87*
45	*33.32*	**120**	*19.75*	**195**	*39.33*	**270**	*18.59*	**345**	*35.59*
50	*32.75*	**125**	*19.81*	**200**	*39.10*	**275**	*19.80*	**350**	*34.59*
55	*32.17*	**130**	*20.03*	**205**	*32.22*	**280**	*21.32*	**355**	*33.82*
60	*31.54*	**135**	*20.43*	**210**	*27.44*	**285**	*23.31*	**360**	*33.28*
65	*30.67*	**140**	*21.28*	**215**	*23.95*	**290**	*26.09*		
70	*29.65*	**145**	*22.40*	**220**	*21.86*	**295**	*29.93*		
						Featherline		**35°**	*34.32*
						Cone Top Plane		**170°**	*37.90*
						Profile		**185°**	*39.16*
						Cone Top Plane		**200°**	*39.10*
						Featherline		**320°**	*43.96*

Cross-Section Number: 13
Step of measurement, mm: 10
Distance from the Heel Point, mm: 75

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*35.05*	**75**	*28.00*	**150**	*23.69*	**225**	*19.53*	**300**	*32.91*
5	*34.66*	**80**	*26.20*	**155**	*25.56*	**230**	*18.61*	**305**	*36.45*
10	*34.30*	**85**	*24.34*	**160**	*28.38*	**235**	*17.65*	**310**	*41.02*
15	*34.32*	**90**	*23.35*	**165**	*32.28*	**240**	*17.70*	**315**	*43.89*
20	*34.43*	**95**	*21.95*	**170**	*36.01*	**245**	*16.87*	**320**	*45.96*
25	*34.46*	**100**	*21.16*	**175**	*42.64*	**250**	*16.96*	**325**	*44.53*
30	*33.47*	**105**	*20.55*	**180**	*42.33*	**255**	*16.98*	**330**	*42.69*
35	*33.48*	**110**	*19.78*	**185**	*42.03*	**260**	*17.25*	**335**	*37.87*
40	*33.31*	**115**	*19.47*	**190**	*41.98*	**265**	*17.68*	**340**	*38.25*
45	*32.96*	**120**	*19.29*	**195**	*42.19*	**270**	*16.33*	**345**	*36.91*
50	*32.52*	**125**	*19.44*	**200**	*35.10*	**275**	*19.48*	**350**	*35.92*
55	*32.06*	**130**	*19.70*	**205**	*30.13*	**280**	*17.96*	**355**	*35.35*
60	*31.31*	**135**	*20.30*	**210**	*25.02*	**285**	*22.71*	**360**	*34.77*
65	*30.55*	**140**	*21.07*	**215**	*22.42*	**290**	*24.95*		
70	*29.17*	**145**	*22.20*	**220**	*21.35*	**295**	*28.73*		
						Featherline		**25°**	*34.46*
						Cone Top Plane		**175°**	*42.64*
						Profile		**185°**	*42.03*
						Cone Top Plane		**195°**	*42.19*
						Featherline		**320°**	*45.96*

Cross-Section Number: 14
Step of measurement, mm: 10
Distance from the Heel Point, mm: 85

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*37.66*	**75**	*26.49*	**150**	*24.31*	**225**	*19.71*	**300**	*32.65*
5	*36.91*	**80**	*27.40*	**155**	*26.65*	**230**	*18.69*	**305**	*37.47*
10	*36.90*	**85**	*23.04*	**160**	*29.57*	**235**	*17.69*	**310**	*41.91*
15	*36.64*	**90**	*21.66*	**165**	*33.18*	**240**	*16.96*	**315**	*45.43*
20	*33.33*	**95**	*20.81*	**170**	*38.69*	**245**	*16.75*	**320**	*48.21*
25	*35.41*	**100**	*19.84*	**175**	*45.82*	**250**	*16.53*	**325**	*48.51*
30	*35.19*	**105**	*19.35*	**180**	*45.36*	**255**	*16.61*	**330**	*46.58*
35	*34.92*	**110**	*18.99*	**185**	*45.22*	**260**	*16.90*	**335**	*44.09*
40	*34.51*	**115**	*18.93*	**190**	*45.03*	**265**	*17.30*	**340**	*42.23*
45	*34.00*	**120**	*19.05*	**195**	*45.53*	**270**	*17.95*	**345**	*40.58*
50	*33.42*	**125**	*19.29*	**200**	*35.53*	**275**	*18.86*	**350**	*39.18*
55	*32.81*	**130**	*16.66*	**205**	*29.34*	**280**	*19.85*	**355**	*38.20*
60	*31.58*	**135**	*20.53*	**210**	*25.56*	**285**	*21.64*	**360**	*37.59*
65	*30.25*	**140**	*21.43*	**215**	*22.84*	**290**	*24.15*		
70	*28.33*	**145**	*22.78*	**220**	*20.90*	**295**	*27.64*		
						Featherline		**20°**	*33.33*
						Cone Top Plane		**175°**	*45.82*
						Profile		**185°**	*45.22*
						Cone Top Plane		**195°**	*45.53*
						Featherline		**322°78'**	*48.87*

Cross-Section Number: 15
Step of measurement, mm: 5
Distance from the Heel Point, mm: 90

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*39.41*	**75**	*30.36*	**150**	*26.22*	**225**	*19.16*	**300**	*30.75*
5	*38.76*	**80**	*28.58*	**155**	*28.26*	**230**	*18.51*	**305**	*35.86*
10	*38.48*	**85**	*26.43*	**160**	*32.31*	**235**	*17.46*	**310**	*41.98*
15	*38.31*	**90**	*24.23*	**165**	*37.13*	**240**	*17.07*	**315**	*46.15*
20	*37.94*	**95**	*22.73*	**170**	*44.67*	**245**	*16.40*	**320**	*49.37*
25	*36.88*	**100**	*21.20*	**175**	*43.67*	**250**	*16.38*	**325**	*52.14*
30	*32.70*	**105**	*20.32*	**180**	*47.09*	**255**	*16.43*	**330**	*48.98*
35	*36.59*	**110**	*19.74*	**185**	*46.97*	**260**	*16.50*	**335**	*46.51*
40	*36.10*	**115**	*19.19*	**190**	*46.90*	**265**	*17.05*	**340**	*44.28*
45	*35.54*	**120**	*18.94*	**195**	*43.16*	**270**	*17.63*	**345**	*42.24*
50	*35.58*	**125**	*18.81*	**200**	*35.39*	**275**	*18.41*	**350**	*41.24*
55	*34.95*	**130**	*18.85*	**205**	*28.71*	**280**	*19.51*	**355**	*40.12*
60	*34.10*	**135**	*20.38*	**210**	*25.33*	**285**	*21.19*	**360**	*39.28*
65	*33.17*	**140**	*21.20*	**215**	*22.18*	**290**	*23.20*		
70	*31.90*	**145**	*22.51*	**220**	*20.61*	**295**	*26.69*		
						Featherline		**20°**	*37.94*
						Cone Top Plane		**177°03'**	*47.41*
						Profile		**185°**	*46.97*
						Cone Top Plane		**193°80'**	*47.17*
						Featherline		**325°**	*52.14*

Cross-Section Number: 16
Step of measurement, mm: 5
Distance from the Heel Point, mm: 95

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*41.64*	**75**	*25.89*	**150**	*23.86*	**225**	*19.39*	**300**	*19.98*
5	*40.72*	**80**	*24.10*	**155**	*25.83*	**230**	*18.34*	**305**	*35.38*
10	*40.31*	**85**	*22.38*	**160**	*28.73*	**235**	*17.40*	**310**	*41.62*
15	*39.76*	**90**	*21.43*	**165**	*31.09*	**240**	*18.85*	**315**	*46.78*
20	*38.81*	**95**	*20.07*	**170**	*36.46*	**245**	*16.50*	**320**	*50.38*
25	*38.64*	**100**	*19.50*	**175**	*42.32*	**250**	*16.20*	**325**	*52.07*
30	*38.11*	**105**	*19.15*	**180**	*49.05*	**255**	*16.17*	**330**	*50.50*
35	*37.45*	**110**	*19.46*	**185**	*48.52*	**260**	*16.45*	**335**	*48.23*
40	*36.81*	**115**	*18.38*	**190**	*48.64*	**265**	*16.82*	**340**	*46.38*
45	*36.09*	**120**	*18.64*	**195**	*42.06*	**270**	*17.52*	**345**	*44.75*
50	*35.15*	**125**	*18.92*	**200**	*33.95*	**275**	*18.21*	**350**	*42.44*
55	*34.02*	**130**	*19.35*	**205**	*28.42*	**280**	*19.17*	**355**	*42.59*
60	*32.43*	**135**	*20.16*	**210**	*24.98*	**285**	*20.66*	**360**	*4159*
65	*30.49*	**140**	*20.96*	**215**	*23.07*	**290**	*22.45*		
70	*28.34*	**145**	*22.22*	**220**	*20.24*	**295**	*24.92*		
						Featherline		**15°**	*39.76*
						Cone Top Plane		**178°79'**	*49.04*
						Profile		**185°**	*48.52*
						Cone Top Plane		**190°**	*48.64*
						Featherline		**325°**	*52.07*

Cross-Section Number: 17
Step of measurement, mm: 5
Distance from the Heel Point, mm: 100

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*43.60*	**75**	*26.00*	**150**	*23.39*	**225**	*18.79*	**300**	*26.61*
5	*43.01*	**80**	*23.73*	**155**	*25.33*	**230**	*18.24*	**305**	*33.02*
10	*42.39*	**85**	*22.28*	**160**	*27.76*	**235**	*16.83*	**310**	*39.99*
15	*41.09*	**90**	*20.90*	**165**	*30.14*	**240**	*16.91*	**315**	*47.13*
20	*40.92*	**95**	*19.78*	**170**	*35.66*	**245**	*16.66*	**320**	*51.64*
25	*40.38*	**100**	*19.20*	**175**	*40.75*	**250**	*15.94*	**325**	*55.60*
30	*39.70*	**105**	*19.21*	**180**	*48.72*	**255**	*15.84*	**330**	*53.75*
35	*39.15*	**110**	*18.90*	**185**	*50.02*	**260**	*16.05*	**335**	*51.88*
40	*38.24*	**115**	*18.34*	**190**	*46.78*	**265**	*16.27*	**340**	*48.60*
45	*37.26*	**120**	*18.39*	**195**	*41.66*	**270**	*16.76*	**345**	*47.52*
50	*36.08*	**125**	*18.34*	**200**	*30.37*	**275**	*17.43*	**350**	*46.10*
55	*34.73*	**130**	*18.64*	**205**	*28.32*	**280**	*18.13*	**355**	*44.46*
60	*32.94*	**135**	*19.06*	**210**	*24.42*	**285**	*19.76*	**360**	*43.55*
65	*30.75*	**140**	*19.75*	**215**	*22.09*	**290**	*21.53*		
70	*28.22*	**145**	*21.68*	**220**	*20.30*	**295**	*23.67*		
						Featherline		**13°04'**	*41.75*
						Profile		**185°**	*50.02*
						Featherline		**325°96'**	*55.43*

Cross-Section Number: 18
Step of measurement, mm: 10
Distance from the Heel Point, mm: 110

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*49.40*	**75**	*24.62*	**150**	*22.27*	**225**	*17.94*	**300**	*23.53*
5	*48.49*	**80**	*22.71*	**155**	*24.45*	**230**	*16.73*	**305**	*30.97*
10	*47.76*	**85**	*21.15*	**160**	*26.98*	**235**	*16.19*	**310**	*37.83*
15	*45.76*	**90**	*20.06*	**165**	*29.90*	**240**	*15.94*	**315**	*46.92*
20	*45.31*	**95**	*19.21*	**170**	*32.89*	**245**	*15.63*	**320**	*53.53*
25	*44.78*	**100**	*18.60*	**175**	*37.33*	**250**	*15.51*	**325**	*59.27*
30	*43.86*	**105**	*18.01*	**180**	*40.92*	**255**	*15.35*	**330**	*60.53*
35	*42.65*	**110**	*17.94*	**185**	*42.17*	**260**	*15.43*	**335**	*57.23*
40	*41.38*	**115**	*17.71*	**190**	*40.01*	**265**	*15.67*	**340**	*55.04*
45	*39.94*	**120**	*17.81*	**195**	*36.03*	**270**	*16.14*	**345**	*55.40*
50	*38.16*	**125**	*18.04*	**200**	*31.56*	**275**	*16.76*	**350**	*51.68*
55	*36.12*	**130**	*18.64*	**205**	*26.69*	**280**	*17.60*	**355**	*50.83*
60	*33.09*	**135**	*19.23*	**210**	*23.58*	**285**	*18.92*	**360**	*49.12*
65	*30.62*	**140**	*20.09*	**215**	*20.78*	**290**	*20.42*		
70	*27.61*	**145**	*21.17*	**220**	*19.17*	**295**	*22.37*		
						Featherline		**10°**	*47.76*
						Profile		**185°**	*42.17*
						Featherline		**327°77'**	*60.83*

Cross-Section Number: 19
Step of measurement, mm: 5
Distance from the Heel Point, mm: 115

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*52.47*	**75**	*24.43*	**150**	*20.72*	**225**	*17.80*	**300**	*24.56*
5	*51.52*	**80**	*22.47*	**155**	*22.09*	**230**	*16.88*	**305**	*29.28*
10	*50.35*	**85**	*20.73*	**160**	*23.08*	**235**	*16.13*	**310**	*36.56*
15	*48.75*	**90**	*19.40*	**165**	*25.79*	**240**	*15.50*	**315**	*45.16*
20	*47.80*	**95**	*18.73*	**170**	*28.37*	**245**	*15.24*	**320**	*54.46*
25	*47.53*	**100**	*17.93*	**175**	*31.54*	**250**	*15.02*	**325**	*60.42*
30	*46.16*	**105**	*17.76*	**180**	*34.94*	**255**	*14.92*	**330**	*63.12*
35	*44.91*	**110**	*17.52*	**185**	*37.67*	**260**	*15.01*	**335**	*60.02*
40	*43.20*	**115**	*17.36*	**190**	*36.93*	**265**	*15.20*	**340**	*58.03*
45	*41.37*	**120**	*17.41*	**195**	*33.17*	**270**	*16.63*	**345**	*56.57*
50	*39.45*	**125**	*17.55*	**200**	*29.65*	**275**	*16.24*	**350**	*55.00*
55	*36.51*	**130**	*17.67*	**205**	*25.61*	**280**	*17.17*	**355**	*53.80*
60	*33.53*	**135**	*18.19*	**210**	*22.62*	**285**	*18.23*	**360**	*52.23*
65	*30.04*	**140**	*18.79*	**215**	*20.67*	**290**	*19.72*		
70	*27.06*	**145**	*19.71*	**220**	*18.83*	**295**	*21.94*		
						Featherline		**10°**	*50.35*
						Profile		**185°**	*37.67*
						Featherline		**328°51'**	*63.29*

Cross-Section Number: 20
Step of measurement, mm: 5
Distance from the Heel Point, mm: 120

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*54.47*	**75**	*23.53*	**150**	*20.98*	**225**	*17.27*	**300**	*25.06*
5	*52.67*	**80**	*21.40*	**155**	*22.51*	**230**	*15.99*	**305**	*32.72*
10	*52.88*	**85**	*20.09*	**160**	*24.58*	**235**	*15.28*	**310**	*43.94*
15	*51.33*	**90**	*19.02*	**165**	*26.36*	**240**	*15.20*	**315**	*55.27*
20	*50.41*	**95**	*18.37*	**170**	*29.29*	**245**	*14.83*	**320**	*61.90*
25	*49.85*	**100**	*17.70*	**175**	*31.87*	**250**	*14.52*	**325**	*67.92*
30	*48.87*	**105**	*17.35*	**180**	*33.64*	**255**	*14.46*	**330**	*64.34*
35	*46.98*	**110**	*17.06*	**185**	*33.98*	**260**	*14.52*	**335**	*61.94*
40	*45.06*	**115**	*16.86*	**190**	*32.79*	**265**	*14.71*	**340**	*59.62*
45	*42.74*	**120**	*16.99*	**195**	*29.79*	**270**	*15.11*	**345**	*57.84*
50	*40.11*	**125**	*17.11*	**200**	*26.79*	**275**	*15.48*	**350**	*56.69*
55	*36.81*	**130**	*17.56*	**205**	*23.51*	**280**	*16.15*	**355**	*55.66*
60	*32.98*	**135**	*18.24*	**210**	*21.28*	**285**	*17.43*	**360**	*54.46*
65	*29.85*	**140**	*18.82*	**215**	*19.48*	**290**	*18.54*		
70	*26.31*	**145**	*19.80*	**220**	*17.74*	**295**	*20.54*		
						Featherline		**10°**	*52.88*
						Profile		**185°**	*33.98*
						Featherline		**330°**	*64.34*

Cross-Section Number: 21
Step of measurement, mm: 5
Distance from the Heel Point, mm: 125

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*58.39*	**75**	*23.38*	**150**	*19.75*	**225**	*16.05*	**300**	*22.29*
5	*57.64*	**80**	*21.31*	**155**	*21.05*	**230**	*15.45*	**305**	*23.31*
10	*56.70*	**85**	*19.65*	**160**	*22.67*	**235**	*14.94*	**310**	*30.21*
15	*54.61*	**90**	*18.37*	**165**	*29.78*	**240**	*14.49*	**315**	*40.89*
20	*53.69*	**95**	*17.84*	**170**	*26.42*	**245**	*14.16*	**320**	*54.90*
25	*52.85*	**100**	*17.06*	**175**	*28.42*	**250**	*13.94*	**325**	*63.38*
30	*51.50*	**105**	*16.68*	**180**	*29.52*	**255**	*13.73*	**330**	*70.06*
35	*49.59*	**110**	*16.18*	**185**	*29.77*	**260**	*14.07*	**335**	*67.23*
40	*47.53*	**115**	*16.05*	**190**	*28.64*	**265**	*14.28*	**340**	*64.29*
45	*44.62*	**120**	*16.10*	**195**	*26.72*	**270**	*14.60*	**345**	*62.35*
50	*41.53*	**125**	*16.32*	**200**	*24.18*	**275**	*15.11*	**350**	*60.79*
55	*37.79*	**130**	*16.72*	**205**	*22.34*	**280**	*15.76*	**355**	*59.58*
60	*34.02*	**135**	*17.28*	**210**	*20.31*	**285**	*16.89*	**360**	*58.31*
65	*29.40*	**140**	*17.78*	**215**	*18.74*	**290**	*18.17*		
70	*26.08*	**145**	*18.62*	**220**	*17.40*	**295**	*19.49*		
						Featherline		**12°58'**	*55.84*
						Profile		**185°**	*29.77*
						Featherline		**330°**	*70.06*

Cross-Section Number: 22
Step of measurement, mm: 10
Distance from the Heel Point, mm: 135

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*63.72*	**75**	*21.02*	**150**	*16.29*	**225**	*13.58*	**300**	*19.42*
5	*63.05*	**80**	*19.08*	**155**	*17.16*	**230**	*12.97*	**305**	*21.92*
10	*62.64*	**85**	*17.94*	**160**	*17.99*	**235**	*12.35*	**310**	*26.33*
15	*62.31*	**90**	*16.89*	**165**	*18.84*	**240**	*11.85*	**315**	*38.86*
20	*60.51*	**95**	*15.91*	**170**	*19.62*	**245**	*12.00*	**320**	*56.66*
25	*58.99*	**100**	*15.07*	**175**	*19.84*	**250**	*11.93*	**325**	*67.04*
30	*57.15*	**105**	*14.87*	**180**	*20.06*	**255**	*12.03*	**330**	*74.02*
35	*54.47*	**110**	*14.53*	**185**	*19.71*	**260**	*12.16*	**335**	*71.89*
40	*51.37*	**115**	*14.38*	**190**	*19.57*	**265**	*12.36*	**340**	*69.81*
45	*47.89*	**120**	*14.08*	**195**	*18.43*	**270**	*12.74*	**345**	*67.64*
50	*43.06*	**125**	*14.37*	**200**	*17.89*	**275**	*13.25*	**350**	*65.84*
55	*37.64*	**130**	*14.59*	**205**	*16.62*	**280**	*13.81*	**355**	*64.79*
60	*29.74*	**135**	*14.60*	**210**	*15.22*	**285**	*14.65*	**360**	*63.65*
65	*27.28*	**140**	*15.13*	**215**	*14.68*	**290**	*15.73*		
70	*23.36*	**145**	*15.69*	**220**	*13.92*	**295**	*17.30*		
						Featherline		**16°36'**	*61.94*
						Profile		**185°**	*19.71*
						Featherline		**329°**	*74.00*

Cross-Section Number: 23
Step of measurement, mm: 8,85
Distance from the Heel Point, mm: 143,85

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*65.16*	**75**	*18.05*	**150**	*11.23*	**225**	*8.86*	**300**	*15.66*
5	*65.74*	**80**	*16.67*	**155**	*11.43*	**230**	*8.79*	**305**	*17.79*
10	*65.88*	**85**	*15.39*	**160**	*11.37*	**235**	*8.25*	**310**	*20.48*
15	*66.00*	**90**	*13.84*	**165**	*11.33*	**240**	*8.32*	**315**	*28.40*
20	*66.81*	**95**	*13.33*	**170**	*11.38*	**245**	*8.77*	**320**	*54.41*
25	*64.70*	**100**	*12.63*	**175**	*11.33*	**250**	*8.86*	**325**	*69.29*
30	*62.32*	**105**	*12.14*	**180**	*11.27*	**255**	*9.05*	**330**	*79.60*
35	*58.70*	**110**	*11.82*	**185**	*10.99*	**260**	*9.12*	**335**	*72.56*
40	*54.79*	**115**	*11.45*	**190**	*10.59*	**265**	*9.41*	**340**	*70.43*
45	*49.89*	**120**	*11.02*	**195**	*10.50*	**270**	*9.88*	**345**	*68.30*
50	*43.07*	**125**	*11.23*	**200**	*10.12*	**275**	*9.39*	**350**	*67.75*
55	*35.64*	**130**	*11.05*	**205**	*10.24*	**280**	*9.89*	**355**	*65.70*
60	*2.910*	**135**	*10.78*	**210**	*9.43*	**285**	*11.56*	**360**	*65.32*
65	*24.44*	**140**	*11.07*	**215**	*9.06*	**290**	*12.83*		
70	*20.28*	**145**	*10.97*	**220**	*9.18*	**295**	*12.97*		
						Featherline		**20°**	*66.81*
						Profile		**185°**	*10.99*
						Featherline		**328°13'**	*74.60*

Cross-Section Number: 24
Step of measurement, mm: 6.15
Distance from the Heel Point, mm: 150

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*65.23*	**75**	*14.52*	**150**	*5.44*	**225**	*4.40*	**300**	*12.03*
5	*65.79*	**80**	*13.03*	**155**	*5.00*	**230**	*4.41*	**305**	*14.36*
10	*65.92*	**85**	*11.35*	**160**	*4.72*	**235**	*4.61*	**310**	*16.28*
15	*66.10*	**90**	*10.26*	**165**	*4.67*	**240**	*4.55*	**315**	*20.77*
20	*66.69*	**95**	*9.38*	**170**	*4.42*	**245**	*4.86*	**320**	*57.44*
25	*67.79*	**100**	*8.89*	**175**	*3.80*	**250**	*4.98*	**325**	*68.78*
30	*65.39*	**105**	*8.44*	**180**	*4.84*	**255**	*5.37*	**330**	*73.66*
35	*61.89*	**110**	*7.46*	**185**	*3.47*	**260**	*5.57*	**335**	*71.87*
40	*56.31*	**115**	*7.22*	**190**	*3.74*	**265**	*5.98*	**340**	*69.74*
45	*50.35*	**120**	*6.82*	**195**	*3.74*	**270**	*6.28*	**345**	*68.41*
50	*43.52*	**125**	*6.77*	**200**	*3.71*	**275**	*6.84*	**350**	*66.93*
55	*34.30*	**130**	*6.24*	**205**	*3.82*	**280**	*7.39*	**355**	*65.94*
60	*25.61*	**135**	*5.93*	**210**	*3.69*	**285**	*8.07*	**360**	*65.38*
65	*20.37*	**140**	*5.51*	**215**	*3.88*	**290**	*9.28*		
70	*17.22*	**145**	*5.56*	**220**	*4.11*	**295**	*10.28*		
						Featherline		**25°**	*67.79*
						Profile		**185°**	*3.47*
						Featherline		**328°42'**	*74.49*

Cross-Section Number: 25
Step of measurement, mm: 5
Distance from the Heel Point, mm: 155

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*65.39*	**75**	*11.17*	**150**	-	**225**	*1.19*	**300**	*6.37*
5	*64.86*	**80**	*5.51*	**155**	-	**230**	*1.08*	**305**	*8.67*
10	*65.08*	**85**	*4.43*	**160**	-	**235**	*1.01*	**310**	*11.95*
15	*65.41*	**90**	*2.85*	**165**	-	**240**	*0.95*	**315**	*17.06*
20	*65.83*	**95**	*2.44*	**170**	-	**245**	*1.04*	**320**	*66.08*
25	*67.17*	**100**	*0.98*	**175**	-	**250**	*1.22*	**325**	*68.62*
30	*66.82*	**105**	*0.01*	**180**	-	**255**	*0.05*	**330**	*72.70*
35	*62.47*	**110**	*0.00*	**185**	*1.77*	**260**	*0.75*	**335**	*70.60*
40	*56.76*	**115**	*0.76*	**190**	*1.59*	**265**	*0.54*	**340**	*68.98*
45	*51.15*	**120**	*0.00*	**195**	*1.35*	**270**	*0.70*	**345**	*67.81*
50	*43.21*	**125**	-	**200**	*0.80*	**275**	*1.04*	**350**	*66.47*
55	*30.44*	**130**	-	**205**	*0.77*	**280**	*1.01*	**355**	*65.57*
60	*19.29*	**135**	-	**210**	*1.09*	**285**	*2.11*	**360**	*65.24*
65	*14.74*	**140**	-	**215**	*0.98*	**290**	*2.57*		
70	*9.95*	**145**	-	**220**	*0.85*	**295**	*3.79*		
						Featherline		**28°**	*67.85*
						Profile		**185°**	*1.77*
						Featherline		**327°65'**	*73.95*

Cross-Section Number: 26
Step of measurement, mm: 10
Distance from the Heel Point, mm: 165

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*62.78*	**75**	-	**150**	-	**225**	*-13.28*	**300**	-
5	*62.62*	**80**	-	**155**	-	**230**	*-16.72*	**305**	-
10	*62.08*	**85**	-	**160**	-	**235**	-	**310**	-
15	*63.17*	**90**	-	**165**	-	**240**	-	**315**	-
20	*63.78*	**95**	-	**170**	-	**245**	-	**320**	*51.50*
25	*64.88*	**100**	-	**175**	*-13.04*	**250**	-	**325**	*66.59*
30	*66.35*	**105**	-	**180**	*-11.84*	**255**	-	**330**	*69.82*
35	*63.78*	**110**	-	**185**	*-9.25*	**260**	-	**335**	*67.26*
40	*58.17*	**115**	-	**190**	*-10.78*	**265**	-	**340**	*65.83*
45	*51.09*	**120**	-	**195**	*-12.70*	**270**	-	**345**	*64.37*
50	*40.93*	**125**	-	**200**	*-11.21*	**275**	-	**350**	*63.49*
55	-	**130**	-	**205**	*-11.17*	**280**	-	**355**	*62.79*
60	-	**135**	-	**210**	*-11.78*	**285**	-	**360**	*62.43*
65	-	**140**	-	**215**	*-11.59*	**290**	-		
70	-	**145**	-	**220**	*-13.04*	**295**	-		
						Featherline		**32°80'**	*67.05*
						Profile		**185°**	*-9.25*
						Featherline		**326°40'**	*70.52*

Cross-Section Number: 27
Step of measurement, mm: 5
Distance from the Heel Point, mm: 170

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*60.93*	75	-	150	-	225	-	300	-
5	*61.02*	80	-	155	-	230	-	305	-
10	*61.16*	85	-	160	-	235	-	310	-
15	*61.60*	90	-	165	-	240	-	315	-
20	*62.35*	95	-	170	-	245	-	320	*41.15*
25	*63.33*	100	-	175	*-16.18*	250	-	325	*51.60*
30	*64.69*	105	-	180	*-13.92*	255	-	330	*67.52*
35	*63.55*	110	-	185	*-15.32*	260	-	335	*66.05*
40	*57.66*	115	-	190	*-15.02*	265	-	340	*64.37*
45	*49.39*	120	-	195	*-14.94*	270	-	345	*63.02*
50	-	125	-	200	*-15.41*	275	-	350	*62.13*
55	-	130	-	205	*-15.75*	280	-	355	*61.41*
60	-	135	-	210	*-16.21*	285	-	360	*60.95*
65	-	140	-	215	*-16.83*	290	-		
70	-	145	-	220	*-18.10*	295	-		
						Featherline		33°31'	*66.04*
						Profile		185°	*-15.32*
						Featherline		328°80'	*67.12*

Cross-Section Number: 28
Step of measurement, mm: 5
Distance from the Heel Point, mm: 175

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*59.17*	75	-	150	-	225	-	300	-
5	*58.88*	80	-	155	-	230	-	305	-
10	*59.19*	85	-	160	-	235	-	310	-
15	*59.51*	90	-	165	-	240	-	315	-
20	*60.13*	95	-	170	-	245	-	320	*47.45*
25	*61.16*	100	-	175	-	250	-	325	*61.00*
30	*62.36*	105	-	180	-	255	-	330	*65.65*
35	*64.32*	110	-	185	*-19.00*	260	-	335	*63.86*
40	*58.68*	115	-	190	-	265	-	340	*62.32*
45	*50.28*	120	-	195	-	270	-	345	*61.18*
50	*38.38*	125	-	200	-	275	-	350	*60.24*
55	-	130	-	205	-	280	-	355	*60.24*
60	-	135	-	210	-	285	-	360	*59.05*
65	-	140	-	215	-	290	-		
70	-	145	-	220	-	295	-		
						Featherline		35°	*64.32*
						Profile		185°	*-19.00*
						Featherline		327°38'	*66.76*

Cross-Section Number: 28
Step of measurement, mm: 5
Distance from the Heel Point, mm: 180

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*57.38*	75	-	150	-	225	-	300	-
5	*57.26*	80	-	155	-	230	-	305	-
10	*57.36*	85	-	160	-	235	-	310	-
15	*57.63*	90	-	165	-	240	-	315	-
20	*58.48*	95	-	170	-	245	-	320	*48.51*
25	*59.52*	100	-	175	-	250	-	325	*59.75*
30	*61.21*	105	-	180	-	255	-	330	*64.02*
35	*62.78*	110	-	185	*-15.00*	260	-	335	*61.31*
40	*56.47*	115	-	190	-	265	-	340	*60.13*
45	*46.39*	120	-	195	-	270	-	345	*58.95*
50	-	125	-	200	-	275	-	350	*58.11*
55	-	130	-	205	-	280	-	355	*57.49*
60	-	135	-	210	-	285	-	360	*57.25*
65	-	140	-	215	-	290	-		
70	-	145	-	220	-	295	-		
						Featherline		35°	*62.78*
						Profile		185°	*-15.00*
						Featherline		327°30'	*64.38*

Cross-Section Number: 29
Step of measurement, mm: 5
Distance from the Heel Point, mm: 185

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*55.25*	75	-	150	-	225	-	300	-
5	*55.20*	80	-	155	-	230	-	305	-
10	*55.57*	85	-	160	-	235	-	310	-
15	*56.13*	90	-	165	-	240	-	315	-
20	*56.83*	95	-	170	-	245	-	320	*45.15*
25	*57.90*	100	-	175	-	250	-	325	*58.13*
30	*57.65*	105	-	180	-	255	-	330	*61.54*
35	*57.70*	110	-	185	*-23.00*	260	-	335	*59.49*
40	*48.71*	115	-	190	-	265	-	340	*58.27*
45	-	120	-	195	-	270	-	345	*57.32*
50	-	125	-	200	-	275	-	350	*56.30*
55	-	130	-	205	-	280	-	355	*55.76*
60	-	135	-	210	-	285	-	360	*55.34*
65	-	140	-	215	-	290	-		
70	-	145	-	220	-	295	-		
						Featherline		34°52'	*59.09*
						Profile		185°	*-23.00*
						Featherline		326°91'	*62.66*

Cross-Section Number: 30
Step of measurement, mm: 10
Distance from the Heel Point, mm: 195

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*51.40*	75	-	150	-	225	-	300	-
5	*51.45*	80	-	155	-	230	-	305	-
10	*51.69*	85	-	160	-	235	-	310	-
15	*52.10*	90	-	165	-	240	-	315	-
20	*52.98*	95	-	170	-	245	-	320	*40.26*
25	*54.10*	100	-	175	-	250	-	325	*52.75*
30	*55.62*	105	-	180	-	255	-	330	*57.47*
35	*53.38*	110	-	185	*-25.00*	260	-	335	*55.51*
40	*45.50*	115	-	190	-	265	-	340	*54.00*
45	-	120	-	195	-	270	-	345	*53.18*
50	-	125	-	200	-	275	-	350	*52.13*
55	-	130	-	205	-	280	-	355	*51.73*
60	-	135	-	210	-	285	-	360	*51.28*
65	-	140	-	215	-	290	-		
70	-	145	-	220	-	295	-		
						Featherline		32°73'	*56.33*
						Profile		185°	*-25.00*
						Featherline		328°05'	*57.67*

Cross-Section Number: 31
Step of measurement, mm: 10
Distance from the Heel Point, mm: 205

°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*47.45*	75	-	150	-	225	-	300	-
5	*47.24*	80	-	155	-	230	-	305	-
10	*41.51*	85	-	160	-	235	-	310	-
15	*42.43*	90	-	165	-	240	-	315	-
20	*49.12*	95	-	170	-	245	-	320	-
25	*49.97*	100	-	175	-	250	-	325	*44.87*
30	*51.42*	105	-	180	-	255	-	330	*53.49*
35	*46.07*	110	-	185	*-25.00*	260	-	335	*51.89*
40	-	115	-	190	-	265	-	340	*50.41*
45	-	120	-	195	-	270	-	345	*49.19*
50	-	125	-	200	-	275	-	350	*48.53*
55	-	130	-	205	-	280	-	355	*47.82*
60	-	135	-	210	-	285	-	360	*47.20*
65	-	140	-	215	-	290	-		
70	-	145	-	220	-	295	-		
						Featherline		31°	*51.56*
						Profile		185°	*-25.00*
						Featherline		328°42'	*52.35*

Cross-Section Number: 32
Step of measurement, mm: 10
Distance from the Heel Point, mm: 215

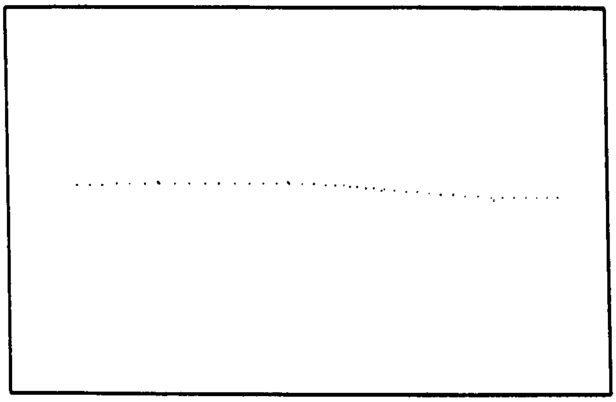
°	R,mm	°	R,mm	°	R,mm	°	R,mm	°	R,mm
0	*43.75*	**75**	-	**150**	-	**225**	-	**300**	-
5	*43.64*	**80**	-	**155**	-	**230**	-	**305**	-
10	*43.67*	**85**	-	**160**	-	**235**	-	**310**	-
15	*44.09*	**90**	-	**165**	-	**240**	-	**315**	-
20	*44.96*	**95**	-	**170**	-	**245**	-	**320**	-
25	*46.07*	**100**	-	**175**	-	**250**	-	**325**	*24.06*
30	*46.34*	**105**	-	**180**	-	**255**	-	**330**	*43.64*
35	*39.60*	**110**	-	**185**	*-23.00*	**260**	-	**335**	*48.03*
40	-	**115**	-	**190**	-	**265**	-	**340**	*46.69*
45	-	**120**	-	**195**	-	**270**	-	**345**	*43.27*
50	-	**125**	-	**200**	-	**275**	-	**350**	*42.59*
55	-	**130**	-	**205**	-	**280**	-	**355**	*42.03*
60	-	**135**	-	**210**	-	**285**	-	**360**	*42.86*
65	-	**140**	-	**215**	-	**290**	-		
70	-	**145**	-	**220**	-	**295**	-		
						Featherline		**28°25'**	*46.76*
						Profile		**185°**	*-23.00*
						Featherline		**332°87'**	*42.70*

Appendix J – Data Files And Representations Of Men's And Ladies' Lasts Shank Curves

J1

Data File And Representation Of Shank Curve Of Ladies' Last With The Heel Height 5 mm

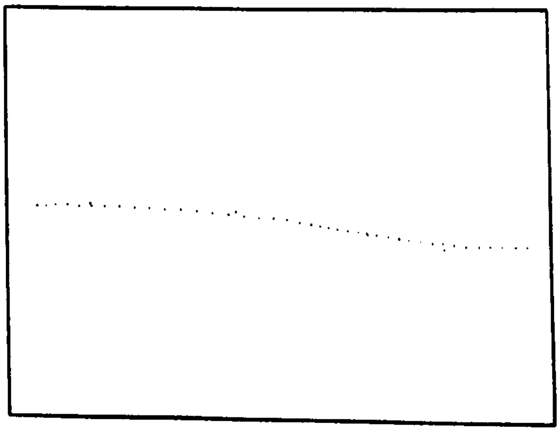
7
38 35
60 36
95 36
110 35
120 33
150 29
167 30



J2

Data File And Representation Of Shank Curve Of Ladies' Last With The Heel Height 10 mm

7
37 44
51 45
90 42
110 38
125 34
145 29
167 30



J3

Data File And Representation Of Shank Curve Of Ladies' Last With The Heel Height 15 mm

7

37 48

60 50

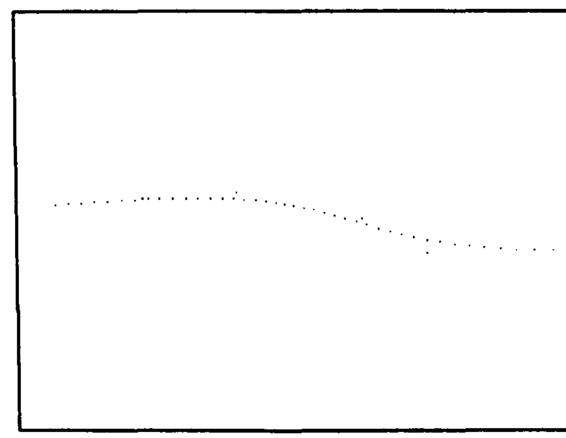
85 52

100 47

118 42

135 29

168 30



J4

Data File And Representation Of Shank Curve Of Ladies' Last With The Heel Height 20 mm

7

38 62

70 56

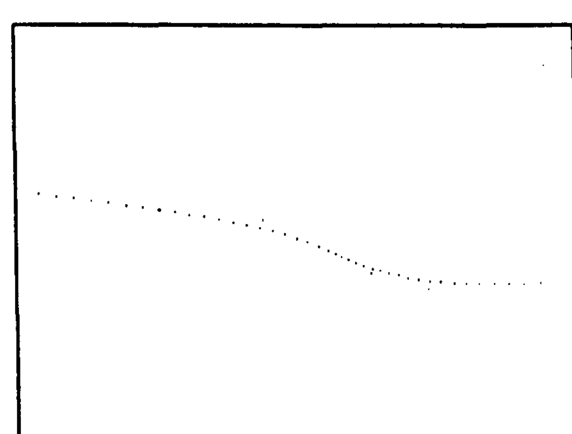
97 53

114 41

125 33

140 27

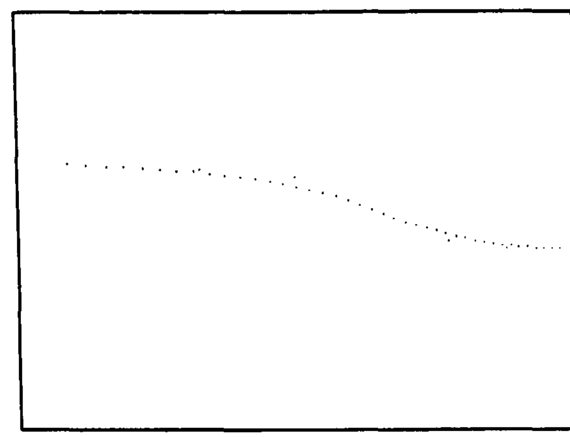
169 30



J5

Data File And Representation Of Shank Curve Of Ladies' Last With The Heel Height 25 mm

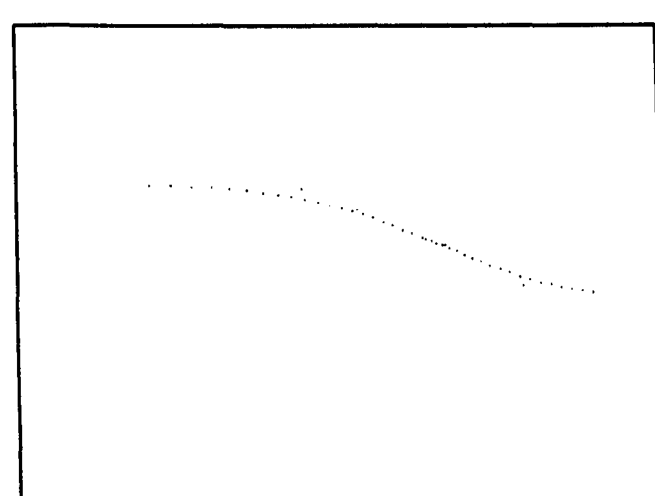
7
40 62
75 60
100 57
120 45
140 33
155 30
169 30



J6

Data File And Representation Of Shank Curve Of Ladies' Last With The Heel Height 30 mm

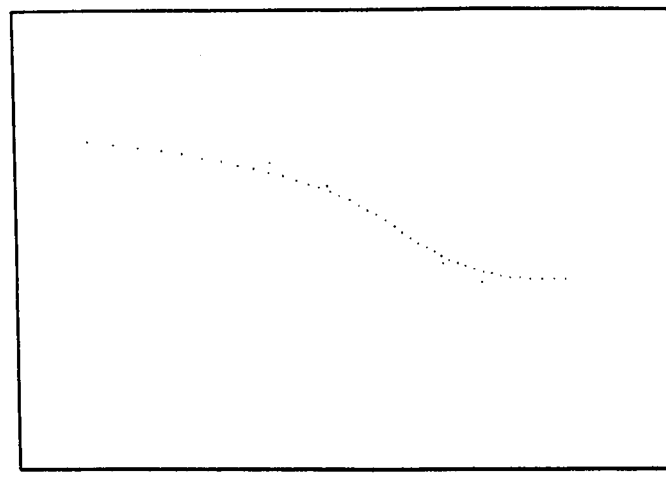
7
37 69
77 68
91 60
108 50
114 47
134 32
152 30



J7

Data File And Representation Of Shank Curve Of Ladies' Last With The Heel Height 40 mm

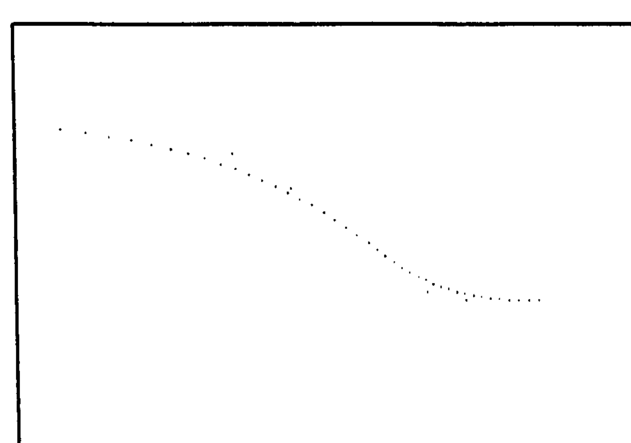
7
37 83
85 75
100 66
115 53
130 36
140 29
162 30



J8

Data File And Representation Of Shank Curve Of Ladies' Last With The Heel Height 50 mm

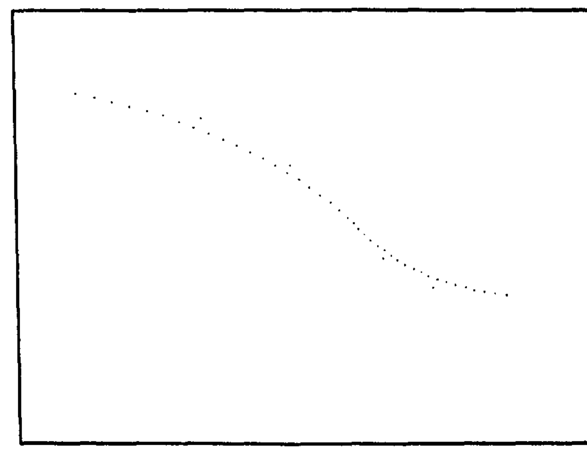
```
7
35 93
80 84
95 71
115 51
130 33
140 30
159 30
```



J9

Data File And Representation Of Shank Curve Of Ladies' Last With The Heel Height 60 mm

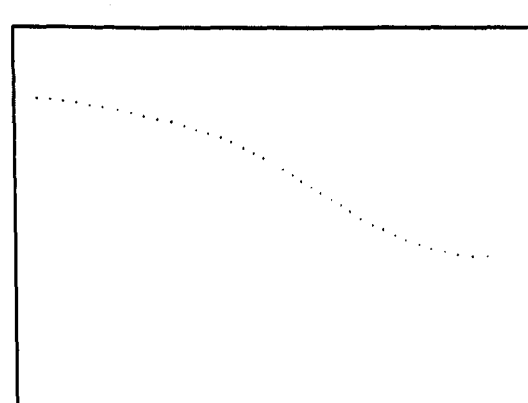
```
7
34 107
67 98
90 80
105 60
114 44
127 33
146 30
```



J10

Data File And Representation Of Shank Curve Of Ladies' Last With The Heel Height 70 mm

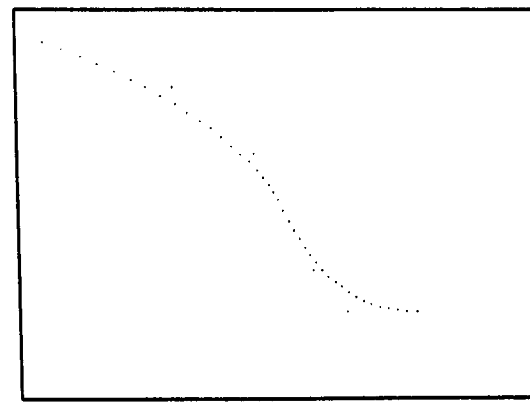
```
7
36.3 90
58.3 87.5
85.5 78.5
101.2 65
117.7 52
133 28
160.6 30
```



J11

Data File And Representation Of Shank Curve Of Ladies' Last With The Heel Height 80 mm

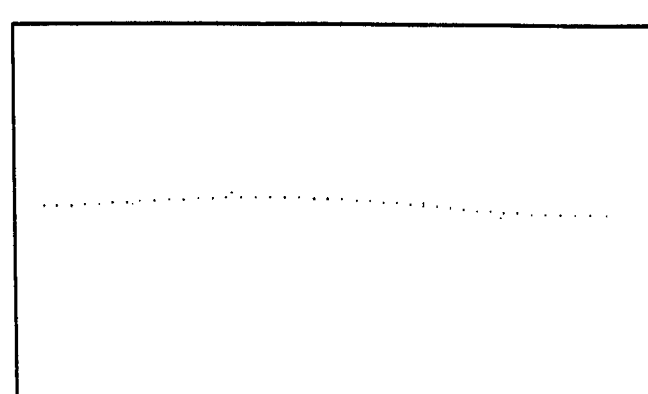
```
7
30 132
64 115
85 90
91 72
100 46
109 30
127 30
```



J12

Data File And Representation Of Shank Curve Of Men's Last With The Heel Height 5 mm

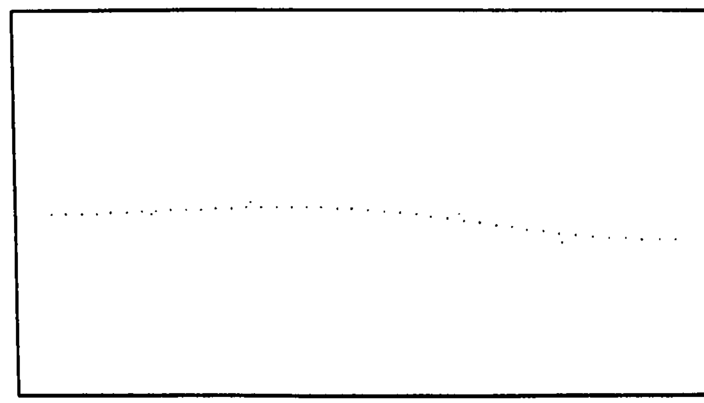
```
7
4.2 42
27.85 43
54 47
79 45
104 44
124 39
151 40
```



J13

Data File And Representation Of Shank Curve Of Men's Last With The Heel Height 10 mm

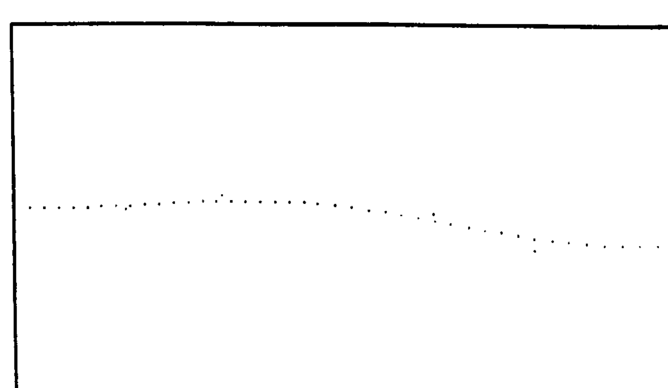
7
6.2 50
32.6 50
59 54.5
85.4 52
113.45 50
140.4 39
170.1 40



J14

Data File And Representation Of Shank Curve Of Men's Last With The Heel Height 15 mm

7
6.2 53
31.5 52
56.8 57
82.1 54.5
111.8 51
138.2 38
170.1 40



J15

Data File And Representation Of Shank Curve Of Men's Last With The Heel Height 20 mm

7
8.4 57

48 57

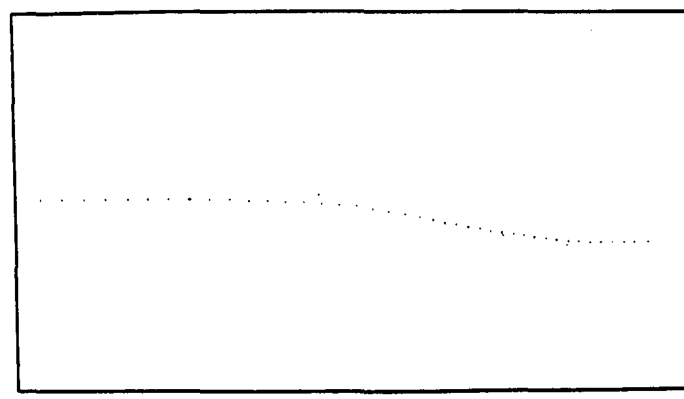
82.1 59

108.5 50

130.5 43

147 39

167.9 40



J16

Data File And Representation Of Shank Curve Of Men's Last With The Heel Height 25 mm

7

5.15 59

33.5 57

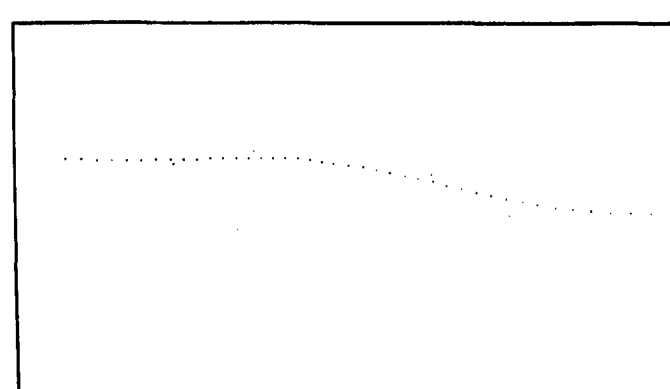
54.5 62

75.5 58

100.7 54

120.65 39

157.4 40



J17

Data File And Representation Of Shank Curve Of Men's Last With The Heel Height 30 mm

7

4.1 65

50.3 62

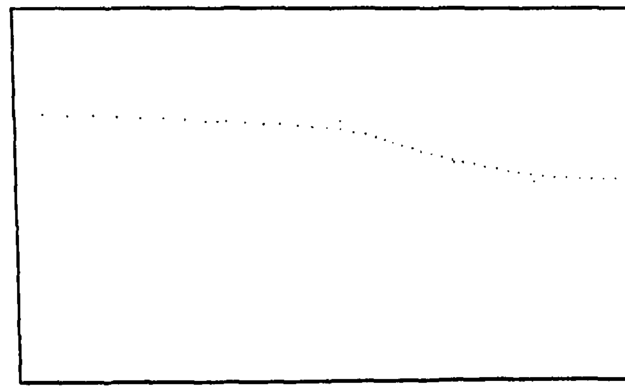
82.85 62

96.5 54

112.25 46

133.25 39

154.25 40



J18

Data File And Representation Of Shank Curve Of Men's Last With The Heel Height 40 mm

7

3.2 72

28 71

53.5 71

75.5 64

101 54

121 39

148 40